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PRACTICAL EXERCISES IN PHYSICAL GEOGRAPHY

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PRACTICAL EXERCISES IN PHYSICAL GEOGRAPHY

BY

WILLIAM MORRIS DAVIS

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GINN & COMPANY

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Prof. W. M. Davis
2-10-33

PREFACE

The object of this Text and the accompanying Atlas is to provide in as compact a form as possible a series of disciplinary exercises which may be assigned as "laboratory work" in connection with any of the modern text-books on Physical Geography.

The need of such exercises is generally recognized. Experience has shown that a student may fail to acquire a clear understanding of the facts and problems of Physical Geography if they are presented only through the text of a printed page; and that even the ornamentation of the page by pertinent illustrations does not always suffice to ensure a full comprehension of essential points. The student's attention must be directed to and detained upon each feature of a complicated fact, each step of a large problem, in order that the facts and problems may reach his understanding and remain in his memory; hence the desirability of combining the performance of a series of systematic exercises with the study of a text.

The topics selected for the Exercises here presented are such as are treated in greater or less fullness in all modern text-books. The Exercises may be taken up in such order as the teacher shall determine: those on the atmosphere and the ocean may follow or precede those on the lands; those on the lands may be rearranged if desired, except that it is well to place Exercise I early in the series because of its many applications, and to place Exercises VII and VIII late in the series because of the greater detail of their problems.

The method recommended for performing the Exercises is stated in the General Instructions (pp. 1 and 2). It may be here added that it will be found useful to allow students to read the Text and to examine the Atlas in a preliminary study period, and thus to

construct mental answers and imaginary diagrams in preparation for oral answers in a recitation or for written and graphic answers in a laboratory period.

The Exercises are not divided into separate lessons; they are left like the chapters of a text-book, to be divided by the teacher according to the time assigned for laboratory work and to the advancement of the pupils. The Exercises are, moreover, planned so that they may be used for a shorter or a longer course, according to the time allotted to Physical Geography in a programme of studies. In a short course all the bracketed questions and sections may be omitted without lessening the continuity of the work. For still more abbreviation, written answers in the pupil's notebook may be replaced by oral answers recited in succession by different members of a class; but it is recommended that after such a recitation the teacher should indicate certain questions for which the answers should be carefully written by all members of the class in order to secure a clear understanding of the most important points.

The Exercises may be profitably extended through a longer course by requiring written answers, carefully phrased, for all questions in the Text. Additional questions, which every teacher will inevitably invent for himself as the work progresses, may be frequently introduced. Questions concerning opportunity for human settlement and movement, conditions of human occupations, etc., may be greatly increased. Some examples of such questions are given, as in Exercise V, §§ 3 and 12; but it has been necessary to exclude them, as a rule, in order to save space. Still further extension of a very profitable kind may be made by having the pupil draw temperature and pressure gradients and generalize wind movements on selected governmental weather maps, following the methods of Exercise XII; or by calling for the preparation of maps, in hachures or contours, of selected parts of the land forms shown in the block diagrams of the Atlas; or by assigning certain parts of selected topographical maps published by governmental surveys for careful description and explanation. But in all cases, whether the work

makes part of a long or of a short course, it is advised that minute accuracy is not to be expected in the answers to questions regarding distances, altitudes, and locations, and that, in general, the answers to questions should be simple rather than elaborate.

The plates in the Atlas on which the Exercises are largely based are in most cases ideal designs and not copies of actual occurrences; but the charts of mean temperatures, prevailing winds, and ocean currents are exceptions to this statement. The reason for giving ideal examples of weather maps and of land forms is, that only in this way can the systematic progress of teaching be secured. In the daily weather maps and on the large-scale topographical maps published by our governmental bureaus, the illustrations of typical features are nearly always complicated by the addition of irrelevant details, which are distracting to the beginner. Moreover, these official maps do not and should not attempt to emphasize certain typical features and to subordinate unessential details; they are prepared for adult experts; they must present the facts of nature in all the complications of their actual occurrence. But to use such maps in the first lessons on Physical Geography would be much the same as to use pages of actual accounts taken from the books of a large commercial establishment in the first lessons in arithmetic, and thus to introduce division, interest, addition, fractions, and so on, in the haphazard order of their daily occurrence in business, instead of in a well-arranged, systematic order appropriate for a beginner's study in school.

The author is, however, aware of various imperfections in the ideal diagrams of the Atlas. Effort was made to find a professional draftsman who would prepare thoroughly satisfactory drawings, but no one could be discovered who possessed at once a sufficient knowledge of the subject and a trained proficiency of handiwork. Among the shortcomings which a redrawing might lessen are certain errors of perspective in some of the block diagrams; some unintentional disagreement of scales among the successive members of a single series of diagrams; an insufficient depth in the gorge between lakes

A and *C*, in 17 2 (for manner of reference to Plates and Figures see p. 1), and a lack of expressive emphasis in the shading of the sea cliffs in 35 1. It is hoped that these subordinate defects will not seriously interfere with the usefulness of the diagrams for the purposes of teaching.

The importance of associating actual phenomena, as they occur in nature, with the ideal types given in the Atlas is fully recognized. A step towards such association is made by introducing in Plates 35–39 a number of maps, reproduced with more or less simplification from parts of selected topographical sheets of different areas in the United States, published by the National Geological Survey (see explanation of plates, page 3 of Atlas), and by calling for the location of these actual examples, as well as of a number of other examples indicated by name in the Text, on the outline maps of the United States and the continents, Plates 40–45. All these actual examples should be carefully learned by name and location in order to give reality to the Exercises. Just as the condensed statements of a text-book should be elaborated by the teacher and illustrated by the exhibition of appropriate maps, pictures, and specimens, so this Text and its Atlas may be profitably supplemented by the exhibition of selected weather maps, published by the Weather Bureau, Department of Agriculture; by the study of full-sized topographical maps published by various governmental bureaus; and by the examination of such photographs and lantern slides as may be available to illustrate the problems in hand. If experimental illustrations of the formation of valleys, deltas, shore cliffs, volcanoes, etc., can be given in what has been called the "wet laboratory," following the suggestions that have recently been made by some expert teachers, so much the better.

Field excursions are also to be strongly recommended as a means of giving reality to problems that might otherwise be regarded as abstractions. It is particularly urged that the Exercises here presented should not be taken to replace field excursions; but rather that the principles illustrated in the Exercises should, as far as

possible, be given additional illustration by systematic excursions in the school district. It is in connection with such excursions that the teacher may to best advantage first teach something of different kinds of rocks, taken from their actual outcrops and selected to illustrate varying degrees of resistance to weathering. Alluvial deposits of gravel, sand, and clay should also be examined in field study. Similarly, local weather observations should be undertaken for the determination of temperatures, wind directions, changes from clear to cloudy sky, rainfall, and so on. It will be of decided advantage if the chief facts concerning the sun's seasonal change of altitude and the associated changes in the points of sunrise and sunset, and of the length of day and night, can be introduced in an earlier year than the one in which these Exercises are studied. If this is not conveniently possible, then the most important observations on the sun, as referred to in Exercise X, §§ 4, 5, should be made while the Exercises on land forms are studied; and the Exercises on the atmosphere should come near the close of the year.

It would truly be vastly better if, in the study of land forms, actual examples of all typical features could be made the subject of systematic observation and description in the field by every pupil, and if in the study of the temperatures, winds, and ocean currents of different parts of the world, the class could visit the regions where the actual phenomena are observable; but this is manifestly impossible. Even the most favored school district does not include a complete and well-ordered series of all the different kinds of land forms which every student of Physical Geography should learn to know; indeed, such forms as it includes are often imperfect or complicated examples of their kind, and it is not always possible for a class to visit them on the day and hour when they are reached in the regular progress of class work. Hence the necessity of presenting the facts of our science largely through descriptions and imitative illustrations. Nevertheless, so great is the power of the constructive imagination on the part of young students that no serious difficulty should be found in giving sufficient reality to the charts

of temperatures, winds, and currents, which graphically represent average values of observed phenomena in Exercises X, XI, and XIII; or to block diagrams such as illustrate the series of volcanic forms in Exercise VI; or to maps such as illustrate the series of shore-line forms in Exercise IX.

It is believed that great progress can be made when imitative ideal illustrations are used as the basis of practical work under the direction of a good teacher and in association with an appropriate text-book. It goes without saying that, as already noted above, supplementary illustrations are useful and helpful; but the effort has been made to provide so much of the essential material in this Text and its Atlas that the labor of the teacher in supplementing it shall be as light as possible. The careful performance of the Exercises will lead the pupil to observe, to describe, and to generalize; to make inferences, to invent explanations, and to test theories; to express new ideas verbally and graphically. If the teacher is patient and does not infringe too often on the pupil's right of discovery, the pupil may make so much progress in these various processes, and at the same time acquire so good a knowledge of a great group of natural phenomena, that he will really be led to make a beginning in the formation of scientific habits of thought.

The value of practical exercises in association with text-book lessons may be illustrated by comparing the impression made upon a student by the study of the important generalization, found ready-made on a printed page, concerning the slopes of rivers and the accordant junctions of branch and main streams, with the impression made upon him by having to develop the generalization himself on the basis of a diagram of river profiles that he has constructed with his own hands, as in Exercise I, § 4. There can be little question that the reality of the facts involved, and the truth of the generalization that represents the relations of the facts, are best apprehended through practical exercises; but at the same time it may well be that the wording of the generalization is not so clearly given in the student's notebook as in the text-book, where it should

therefore be carefully learned. Again, compare the strength of conviction regarding the features and relations of antecedent rivers, according as they are studied in the paragraph of a text-book or worked out by some such method as is offered in Exercise V, § 8; yet the paragraph in the text-book is a valuable supplement to the results of the practical exercise. Compare the clearness and fullness of conception of the phenomena of river capture and the associated features, according as they are learned in a text-book or worked out by means of illustrative diagrams showing the successive stages of the processes involved, in some such way as is suggested in Exercise IX, §§ 4, 5, 6. Furthermore, the value of the careful analysis of a problem and of the successive presentation of its parts in systematically arranged diagrams is illustrated in Exercise XII. There can be little question that such weather maps as those of Plate 33, even though they are only ideal diagrams, will introduce the problem of weather changes much better than can be done by basing the work immediately on governmental weather maps.

Large generalizations must be given abundant and repeated opportunity to establish themselves in the mind. It is for this reason that so many returns are made in Exercises I–IX to the problem of the Geographical Cycle and to the systematic succession in the development of land forms that it embodies. The explanatory method that has long been employed in the study of the air and the oceans is here introduced in the treatment of the lands as well, where its thoroughgoing application constitutes the greatest advance made in Physical Geography in the last century. But it is important to remember that in all cases where land forms are described in terms of the processes involved in producing them, the attention of the geographer should be held primarily to the forms thus produced, and given only secondarily to the processes to which they are due. The systematic advance in the development of these forms, involved in the scheme of the Geographical Cycle, has in recent years suggested the use of such terms as *young*, *mature*, and *old*. The scheme of the Cycle once being known, a valley and its stream may

be described as "young"; and the student is thereby most easily led to apprehend all the characteristic features of the valley in their natural occurrence. A group of mountains may be described as approaching old age, and thus their essential features are most easily brought to mind. A shore line may be described as mature, because in this way the natural association of its parts is most concisely indicated. There can be no question that the figurative use of these organic terms has contributed greatly to the understanding and the enlivenment of Geography.

The preference and experience of the teachers who use this Text may be called upon to decide whether the Exercises shall, step by step, precede or follow the study of a text-book. Good work may be done in either order. References are frequently inserted in the Text to several recent text-books, whereby the pupil is led at once to explanations or definitions needed; but, in general, the Exercises are presented in so great detail that they are largely self-explanatory; hence it is relatively immaterial whether they are used before or after a text, as far as the difficulty of the work is concerned; but it is the belief of the author that the more scientific procedure is to perform the Exercises first and to study the corresponding parts of a text afterwards. In no case, however, is it intended that the performance of the Exercises should replace the careful study of a text-book, where many subjects for which no space can be found in a laboratory manual are introduced and concisely explained and defined.

The author desires to thank his friends, Professor D. W. Johnson of Harvard University, Mr. Charles R. Allen of the New Bedford High School, Mr. Sumner W. Cushing of the Salem Normal School, and Mr. W. L. W. Field of Milton Academy, who have patiently and critically read the proof of the Text, with the result of contributing many practical suggestions, greatly to the improvement of the Exercises. The preparation of the Text and the Atlas has truly been a long and laborious task; but it is hoped that the labor thus expended may not be without its reward in the way of giving some

understanding and enjoyment of a great and delightful subject to the many students who may not pursue it beyond an elementary course in school or college, but who will frequently encounter it in the world at large; and in the way of providing a good foundation for further work by those who wish to gain a scholarly acquaintance with Geography in more advanced courses of study.

W. M. D.

HARVARD UNIVERSITY

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EXERCISES IN PHYSICAL GEOGRAPHY

GENERAL INSTRUCTIONS

In performing the exercises here presented, each pupil should have this Manual, the accompanying Atlas, and an ordinary Notebook on his desk.

The Manual gives directions and questions. The answers to the questions are to be found by studying the figures in the Atlas, and then they are to be written in the Notebook. The directions usually require some simple drawing in the Atlas or Notebook.

References to the plates and figures of the Atlas are made by two numbers; the first number, in smaller type, refers to the plate; the second number, in larger type, refers to the figure. For example, 6 12 means Plate 6, Figure 12. When a plate is referred to without mention of any figure, the plate number is preceded by the word Plate.

References to certain text-books, where explanations of various topics may be found, are made by initial letters, followed by numbers which indicate the page and fraction (ninths) of a page intended A dash after a page number indicates a longer reference than usual. *DE* refers to Davis's Elementary Physical Geography; *DP*, to Davis's Physical Geography; *G*, to Gilbert and Brigham's Introduction to Physical Geography; *T*, to Tarr's New Physical Geography. *U.S.G.S.* means United States Geological Survey.

General explanations within a section are often preceded by the word NOTE. Explanatory phrases or words are inclosed in

parentheses ( ). Bracketed [ ] sections and questions may be omitted in a short course: [blue] and [red] suggest the use of colored crayons, but they are not essential.

Scientific terms, when first used, are printed in *italics;* they are repeated in the final section of each exercise for review.

The letters N., E., S., W., meaning north, east, south, west, are always followed by a period. Italic capital letters without a period refer to the same letters in the figures of the Atlas. Such references as D_1–D_4 mean D_1, D_2, D_3, D_4. Further explanation of the figures is given at the beginning of the Atlas.

At the opening of a day's exercise write in the Notebook the number and name of the exercise, and also the number of the section at which work is begun. Enter the number of each question before its answer. When a new section is begun, enter its number.

Read each question or direction carefully. Then turn to the proper figure in the Atlas and study out the answer. Prepare the answer clearly in the mind before writing it down; then write it accurately in the Notebook, and turn promptly to the next question.

When the directions require drawing in the Atlas or Notebook, consider carefully what is to be done before doing it. See that your pencil is sharp, or your pen clean, before drawing any lines.

Note that in Exercise V the plates are used in the following order: 11, 12, 14, 13, 16; in Exercise VI, in order 17, 18, 20, 19, 15; in Exercise VII, in order 21, 22, 23, 24, 26; in Exercise VIII, in order 27, 25, 28, 29. This arrangement is made so that the plates may be easily compared with each other. By following the references to plates and figures as given in the text there will be no difficulty in finding the proper figure.

EXERCISE I. THE VALLEY SYSTEMS OF THE LANDS

OBJECT. **To explain the general effect of rain and rivers on the lands.**

Preliminary. 1 1 is a bird's-eye view of a "block" of land, as if it had been cut out of the earth's crust. North is toward the far end of the block. The NW. and SE. corners of the block are trimmed off to save space. A mountain range, M_1–M_5, rises in the middle distance; the land slopes from the mountain crest southward to the seashore in the foreground, and northward to an elevated interior basin in the background, from which no rivers escape to the sea. A scale of miles is marked on the S. baseline of the block. The scale of heights, on the W. side of the block, is exaggerated about ten times as compared with the front horizontal scale. Numbers (in large type) to the left of large dots on the rivers indicate distances from the sea in miles; numbers (in smaller type) to the right of the dots and on the mountains indicate altitudes in feet. This exercise uses 1, 2, 1–6.

1. 1. How high is the highest peak of the mountain range in 1 1? About how far is it from the ocean? In what direction does the range extend? In what general direction does river Y flow? 2. Mark in light [blue] lines the path that rain water would follow from A to the ocean; from B; from C; from D_1. 3. Does the greater part of each path lie on a hillside (or mountain-side) slope or along a valley bottom? 4. Which paths unite on the way to the ocean? Draw similar lines to the ocean from D_2–D_5; from E_1–E_3. 5. Suppose a great many such lines were drawn; in what part of their paths would they be separate? in what part united? 6. How are streams formed? 7. What is meant by *ground water*, and how is it related to rain and to streams? (*DE*, 234.3, 236.3; *DP*, 224.4, 226.8; *G*, 100.7, 103.6; *T*, 39.1, 59.5.)

2. 1. Where two streams (or rivers) unite (as near E_4 or E_5), do they approach their junction at the same level, as in 1 2, or at different levels, as in 1 3? 2. In which one of 1 2 and 1 3 may the two valley floors (and streams) be described as "joining at accordant levels" (or as making an "accordant junction")? in which one as "making a discordant junction" (or a "hanging junction")? 3. Do the valleys of 1 1 generally show accordant junctions or discordant (hanging) junctions? 4. Mark [blue] lines along all the streams which unite in 1 1 to form river *V*. 5. What name is given to a system of water courses consisting of a river with all its branches and side streams? (*DE*, 241.5; *DP*, 230.3; *G*, 36.4.) 6. What similar name may be given to all the valleys from which the streams unite to form a single river? 7. How many large valley systems are completely shown S. of the mountain crest in 1 1? 8. Which system is the largest? How long is its longest river?

3. 1. Begin at *F* in 1 1 and draw a broken [red] line to inclose all the land surface from which the rainfall is discharged or drained by the large river *V*. 2. Over how many prominent *peaks* (more than 4000′ high) does the inclosing line pass? 3. Where does it follow a sharp-crested ridge? a broad, rounded ridge? a narrower rounded ridge? Draw a similar line for the smaller river *Y*. 4. What name is given to the drainage areas thus inclosed? to the line separating the drainage areas? (*DE*, 241.9; *DP*, 230.6; *G*, 36.3–5.) 5. Draw a dotted [red] line inclosing the valley or stream basin *A*; inclosing *B*; D_3. 6. Such lines, where they do not follow the *main divides*, may be called *subdivides*. Why? 7. Do *spurs* (branches of the larger ridges) usually form divides or subdivides?

4. 1. What is the altitude of river *Y* 4 mi. from its mouth? At what distance from its mouth is the altitude of river *Y* 160′? What is the altitude of the NE. branch of river *V* at 14 mi. from its mouth? 2. In 2 4 the baseline represents sea level; the spaces between the vertical lines represent distances of two miles; how are altitudes indicated? 3. Mark on these vertical lines (beginning at

the right) the altitudes for successive points on river *VC*. 4. Draw a curve through the points thus marked. 5. What does this curve represent? It may be called the *profile* of river *VC*. 6. Does the profile show the true slope of the river or an exaggerated slope? Why? 7. Mark a cross (×) on this profile where stream *B* joins river *VC*. From this cross construct the profile of stream *B*. 8. Do the same for river E_2; for stream *A*. 9. What part of each profile is steepest? least steep? 10. In what part of the river system (near headwaters or mouth) do the streams make most of their descent (or *fall*) toward sea level? 11. What is (roughly) the descent or *fall* of the headwater streams in feet per mile? of the lower course of river *V*? NOTE: Large rivers, like the Mississippi, flow in their lower course with a fall of only an inch or two in a mile. 12. In what part of 1 1 will the streams run fastest? slowest? Why? 13. Where are the streams of smallest volume? the rivers of greatest volume? Explain.

5. 1. What effect is (usually) produced on stream (or river) beds by the action of running water? Explain (*DE*, 136.2, 245.7; *DP*, 103.7; *G*, 32.1, 35.2; *T*, 52.7). 2. What change will this action gradually produce in the stream and river profiles of 1 1? (See 2 4.) 3. What change has it already produced? 4. How does it happen that the slope of each river leads it so accurately to sea level at the river mouth? 5. In this connection, how can use be made of the phrase *river erosion?* of the term *baselevel?* NOTE: The ocean surface may be called the general *baselevel of erosion* for the continents, because it is the "level base," closer and closer to which the processes of erosion tend to wear down or *degrade* the land. 6. In what part of the *V* river system can the valleys still be most worn down or degraded? Why? 7. Will long-continued river action tend to change 1 2 to 1 3, or 1 3 to 1 2? 8. By what process do you think the accurate accordance of the branching valleys with each other, and of the main valley with sea level, in 1 1 has been brought about? 9. Has the production of the valley system, with its accordant arrangement of parts, probably required a very long or a short time?

6. 1. What is the effect of weather changes, acting for a long time, on a land surface? Explain briefly. (*DE*, 134.8; *DP*, 99.8; *G*, 78.8; *T*, 38.6.) 2. How may the terms *weathering*, *rock waste* (or *land waste*), and *soil* be used in connection with valley *A* (or other parts) of 11? 3. Rain water runs down hillside slopes in wet weather, forming little *rills*. 4. How will the wet-weather rills act on the hillside waste (or soil)? 5. What change will thus be made in the size of the hills? 6. Will this change take place rapidly or slowly? 7. What is the chief source of the water in the streams during dry weather? 8. Why do most streams and rivers become (comparatively) clear when running slowly at times of low water in dry weather, and muddy or turbid when running rapidly at times of flood in wet weather? NOTE: The destructive processes caused by weather changes and stream (river) action may together be given the general name *erosion*. 9. State some of the effects already produced by erosion in 11 near *A*; near D_1; near E_2. 10. State some effects yet to be produced near the same points.

7. 1. Is a greater or less stream velocity needed to wash along, or *transport*, coarse waste (*bowlders* and *gravel*) than fine waste (*sand*, in small grains; *silt*, in very small particles)? 2. In what part of its system can a river transport both coarse and fine waste? only the finer waste? 3. Is a river a better transporter at time of flood or of low water? 4. What happens to coarse, angular waste as it is rolled along the bed of a rapid stream? 5. To what part of 11 will the waste from the *V* valley system be transported? of the *Y* valley system? 6. Why is some of the waste laid down, or *deposited*, near the river mouths? 7. What is the form of the land that has been made of rock waste deposited by rivers near their mouths? 8. What name is given to such forms? Mark them with [blue] dots in 11. 9. Do these forms contain all the waste that has been brought to the river mouths from the headwaters and slopes of the valley systems? 10. Where is the rest of the waste deposited? [11. How is some of this deposit indicated in the S. block face of 11? 12. How has it been spread out?

13. Why is it deposited in layers or *strata?* 14. Has each layer or *stratum* a smooth or a rough surface? 15. Why does the sea-bottom deposit vary in thickness, as shown on the S. face of the block?] 16. State the general principle thus illustrated concerning the removal of land waste. (*DE*, 136.1; *DP*, 103.6; *G*, 59.8; *T*, 52.5.)

8. [1. Suppose that the processes of erosion, transportation, and deposition continue many hundred thousand years. 2. Draw in 2 4 a broken line to show the profile which would then be followed by river *VC* (begin the river head at 2600′); a dotted line to show the profile at a still later time (begin the river head at 1800′). NOTE: The river profile must have a seaward slope, less steep toward the mouth than toward the head; it must not be drawn beneath sea level. 3. Which part of the river shows the greatest change in these profiles? the least change? Why? 4. Will the river then run faster or slower than now? transport more or less waste than now? Why? 5. Imagine that the processes of erosion, transportation, and deposition have already been at work many hundred thousand years before the hills and valleys gained the form shown in 1 1. 6. Draw in 2 4 a profile for an early stage of river *VC*; for a still earlier stage. (The dot-and-dash line in 2 4 may be taken to represent the original profile of the land, before the valleys were eroded. Some early river profiles are partly indicated by three-dot lines.) 7. Compare the profile for 1 1 with the earlier profiles, as to the slope of the main river (near middle course); as to the slope of headwaters. Explain the differences. 8. On which profile would the main river (middle course) flow fastest? slowest? erode its bed fastest? slowest? [9. Explain as fully as you can.] 10. Answer the same (four) questions for the headwaters. [11. Explain.] 12. As the river profiles are worn lower and lower, what happens to the hillsides and hilltops?]

9. If § 8 is omitted, §§ 9, 10 should also be omitted. [1. In 2 6 *MM* is a profile (on a larger scale than 1 1) across one valley and two ridges about ten miles from the sea. A similar cross profile of the

same valley for an earlier stage of its history is indicated by *YY*; for a later stage by *OO*. Draw a profile for a stage between *Y* and *M*; another, between *M* and *O*. 2. In which stage has the valley the narrowest floor and the steepest sides? Why? 3. In which stage the widest floor with the most gently sloping sides? Why? 4. Draw several additional profiles (one earlier than *YY*, one later than *OO*). 5. Describe the form that the district would have when all its valleys come to have cross profiles like the latest profile. 6. Why may such a district be called a *peneplain?* What is the relation of a peneplain to its baselevel? (*DE*, 206.2; *DP*, 152.5; *G*, 161.4; *T*, 58.5.) 7. In which stage are the valleys deepened faster than the hills are worn down? In which stage are the hills worn down faster than the valleys are deepened? [8. Explain as fully as you can.] 9. In which stage are the hills worn down most slowly? Why? 10. Why are the hills worn down faster in this stage than the valleys are then deepened?]

10. If § 9 is omitted, omit § 10 also. [1. In which profile of 2 4 might the river be appropriately called *young? old?* 2. In which cross profiles of 2 6 might the valley be called *young? old?* 3. What term (indicating stage of development) might be as appropriately applied to the cross profile of the valley *MM*, 2 6? to the river *VC*, 1 1? (*DE*, 269.8; *DP*, 250.6; *G*, 58.3; *T*, 57.3.) 4. If an old land surface or peneplain were very slowly given a greater altitude by a broad uplift of its region, what change would take place in the behavior of its rivers? 5. Why might the rivers then be described as "made young again"? or as *rejuvenated?* or as *revived?* 6. What event presumably took place in the region of 1 1, before young valleys could be eroded? Why? NOTE: The long period of time in which the general processes of erosion will wear down any uplifted region to a low peneplain may be called *a cycle of erosion.* The features of the land surface in the early, intermediate, and late stages of a cycle may be spoken of as *young, mature,* and *old.* 7. Compare young and old rivers, as to slope; as to velocity; as to the power of transportation; as to rate of valley

deepening. 8. Compare the rivers of 11 with young rivers and with old rivers, as to form of profile (see 24); as to depth of valleys (see 26); as to rate of valley deepening; as to amount of waste, or *load*, received from the valley sides; as to *texture* (coarseness or fineness) of waste received. 9. Compare the valleys of a river system in its young, mature, and old stages, as to depth (below the neighboring hills); as to narrowness or openness; as to slope of valley sides. NOTE: The *relief* of a land surface is the general difference of altitude between the valleys and the neighboring hilltops, or the height of the hills above the neighboring valleys. 10. In what stages of a cycle of erosion is the relief of moderate measure (see 26)? of greatest measure? 11. In what stage of a cycle of erosion might the rivers be imagined as saying to one another, "Our work is before us"? "Our work is well advanced"? "Our work is (nearly) done"? 12. Describe briefly the "life history of a river system."]

11. 1. Describe the form of the land margin at N and N_1, 11. Compare it with the margin near the river mouths. 2. How have the cliffs at N and N_1 been produced? (*DE*, 136.8; *DP*, 104.3; *G*, 309.9; *T*, 211.3.) 3. Why do the *sea cliffs* not extend all along the shore? 4. Why are they higher in some places than in others? 5. Why are some of the cliffs not now at the shore line? 6. What becomes of the land waste that is weathered from the cliff face or worn from the cliff base? NOTE: The destructive processes going on along the cliff base and on the shallow sea bottom near shore may be called *marine erosion*, in contrast to the general erosion of the land surface, which may be called *subaërial erosion* (the work of weathering, and of rills, streams, and rivers being here included). 7. Which process, marine erosion or subaërial erosion, works on the greatest amount of land surface in 11? 8. Which process probably gives the greatest amount of waste to the sea?

12. 1. Draw a [red] line in 11 dividing the surface that is drained to the ocean from that drained to the interior lake. 2. The

lake occupies the lowest part of an inclosed or *interior basin*. Has the lake an outlet? 3. What is the (local) baselevel for the streams that flow into the lake? 4. Where do these streams deposit the waste that they bring from their upper valleys? 5. As time passes, will the waste-covered plain bordering the lake be worn lower (*degraded*) or built higher (*aggraded*)? 6. How will this change affect the base-level of the interior basin? 7. How does the water, supplied by the inflowing streams, escape from the lake? (*DE*, 284.1; *DP*, 305.1; *T*, 163.7.) 8. If you were in camp on the lake shore near a stream mouth, where would you get your drinking water? Explain.

13. 1. 2 5 is a map (roughly) representing the SW. part of 1 1, from the mountain crest to the shore line. Print the letters *V* and *Y* on 2 5 in places corresponding to *V* and *Y* in 1 1; also the letters *C*, M_3, M_1, D_1, D_3, D_5, *N*. 2. In 2 5 how are the streams represented? the main divides and the subdivides? the borders of the flat valley floors? 3. Draw a broken [red] line inclosing the drainage basin of river *Y*. 4. What is (about) the length of river *Y*? the breadth of the ridge between the upper parts of valleys *Y* and *V*? 5. In what direction would wet-weather rills flow at *A*? at *B*? 6. What relation exists between the direction of rill flow and the direction of the numerous lines near *A* and *B*? NOTE: These lines may be called "down-slope lines," or *hachures* (pron. *hashures*). They are drawn in belts around the slopes; they should be long and light on gentle slopes, shorter and darker on steep slopes. [Hachures should seldom be drawn perfectly straight or precisely parallel to each other; they should usually be a little curved, and more or less divergent or convergent downhill. In the upper part of 2 5 the hachures are drawn somewhat darker and closer together on the E. and SE. slopes, so as to give more effect of relief.] 7. What is the arrangement of the hachures at the head of a valley? around the end of a spur? 8. What process, described in § 6, takes place along the down-slope lines represented by the hachures? [9. Shade with carefully drawn hachures the upper part of the valley in which D_3 or D_5 lies; one of the spurs between D_3 and D_5. (The three-dot lines

may be used to guide the hachure belts.) 10. Draw additional hachures in the NW., SW., or NE. parts of 25.]

14. 1. How many miles are shown on the scale at the bottom of 25? 2. How can you measure distances on the map, 25, by this scale? 3. Why may such a scale be called a *linear scale?* 4. Beginning at *O* on the linear scale, mark points an inch apart along the scale; how many miles are represented by an inch on the scale? 5. Complete the sentences: "The scale of 25 is —— miles to an inch"; "In the front scale of 11, —— (fraction) of an inch represents a mile." 6. How many inches make a mile? 7. What fraction of an actual distance would represent it on a map of which the scale is a mile to an inch? on a map with a scale of two miles to an inch? [half a mile to an inch (or two inches to a mile)? ten miles to an inch?] on 25? 8. About what scale is represented by the fraction $\frac{1}{62,500}$? $\frac{1}{125,000}$? [$\frac{1}{250,000}$? $\frac{1}{1,000,000}$? $\frac{1}{30,000}$? $\frac{1}{10,000}$?] 9. Why may any one of these fractions be called a *fractional scale?*

15. [1. Over a century ago John Playfair, of Edinburgh, Scotland, wrote as follows: "Every river appears to consist of a main trunk, fed from a variety of branches, each running in a valley proportionate to its size, and all of them together forming a system of valleys, communicating with one another and having such a nice [accurate] adjustment of their declivities that none of them join the principal valley either on too high or too low a level; a circumstance which would be infinitely improbable if each of these valleys were not the work of the stream that flows in it. . . . When the usual form of a river is considered, the trunk divided into many branches which rise at a great distance from one another, . . . it becomes strongly impressed upon the mind that all these channels [valleys] have been cut by the waters themselves; that they have been slowly dug out by the washing and erosion of the land; and that it is by the repeated touches of the same instrument that this curious assemblage of lines [valleys] has been engraved so deeply on the surface of the globe." (Quoted from *Illustrations of the Huttonian Theory of the Earth*, Edinburgh, 1802, pp. 102, 103.)

2. What facts, mentioned in the above quotation, are illustrated in this exercise? 3. What suppositions or theories presented in the quotation are supported by this exercise?] [4. The illustration below represents a model which shows mountains bordering the sea. Name some features there represented which have been studied in this exercise.]

16. Define the following terms: § 1, ground water; § 2, river system, valley system, accordant and discordant (or hanging) valley junctions; § 3, drainage area, ridge, peak, spur, river basin, divide or water parting, subdivide; § 4, river profile; § 5, river erosion, baselevel of erosion, degrade; § 6, weathering, rock waste, land waste, soil, rill; § 7, bowlders, gravel, sand, silt, transport, deposit, delta, [stratum, strata]; [§ 9, peneplain; § 10, revived river, cycle of erosion, texture of river load, relief;] § 11, sea cliff, marine erosion, subaërial erosion; § 12, interior basin, aggrade; § 13, hachures; § 14, linear scale, fractional scale.

EXERCISE II. A COASTAL PLAIN

OBJECT. **To represent part of a coastal plain on a map, and to describe the form thus represented.**

Preliminary. The numbers on 31 show the altitude or height above sea level, in feet, of many points (dots near the numbers) in a district bordering the sea. The numbers preceded by a negative sign (as -15) indicate a negative altitude; that is, a depth below sea level. This exercise uses 31, 32 (and 48); [also 615 and 351].

1. 1. Draw a light (pencil) line in 31 separating all parts of the surface that are higher than 100′ from all parts that are lower than 100′. This line must pass through all points marked 100; midway between points equally above and below 100, such as 105 and 95; nearer to 95 than to 110; nearer to 105 than to 90. 2. Explain the preceding rules. 3. Draw similar lines separating parts higher and lower than 200′; than 300′; than 0′. Mark the last line heavier than the others. What does this line represent? 4. Do the same for 400′, 500′, 600′. [Intermediate lines for 50′, 150′, 250′, etc., may also be drawn.]

2. 1. Would you ascend or descend (go uphill or downhill, upslope or down-slope) in walking from K to A? from G to H? from H to F? from C to E? along the 100′ line? along any of the lines that you have drawn? 2. Do the (pencil) lines follow slanting or level paths? Lines of this kind are called *contour lines*, or *contours*. 3. What is the (estimated) difference of altitude between H and G? between B and A? between two adjoining contour lines? 4. The last difference is called the *contour interval*. Why?

3. 1. Lay a strip of paper on 31 along the line AB; mark short lines on the edge of the strip opposite A and B and print these letters there; mark dots on the strip edge at the contours of 0′, 100′,

200′, [250′], 300′, and 600′, and indicate by figures the altitude at each contour dot. 2. Now place the strip along the baseline of 3 2; lay off the contour dots between A' and B', and indicate the altitudes to which the dots refer. 3. Copy the vertical scale at A' on the edge of a slip of paper; lay the slip square across the baseline $A'B'$ at the successive contour dots, and mark off points at the altitudes of the corresponding contours above $A'B'$. 4. Draw a line through the points thus determined, and prolong it to the right of B'. 5. What does this line represent? It is called a *profile line*, or *profile*.

4. 1. If you followed the path of the profile AB (or any similar path) across 3 1, on what part of it would you find a steep slope? a gentle slope? 2. How is the difference of slope indicated by the contour lines? Explain. 3. Make a general rule to show how the spacing of contour lines indicates steep and gentle slopes. 4. Draw some short lines (about $\frac{1}{4}''$ long) to show the direction of slope (downhill) near G; some fainter and longer lines (about $\frac{1}{2}''$ long) to show the slope near H; near C. 5. The down-slope lines may be called *hachures* (pron. *hashures*). 6. What is the relative direction of contours and hachures? 7. Draw a dotted line in 3 1 separating the part of gentle slope from the part of steeper slope. NOTE: In the district here represented all the land higher than the dotted line is supposed to be made of resistant rocks covered with a stony soil; all the land of less altitude, of layers or strata of sand, gravel, clay, etc.; each layer or stratum slants gently seaward with the slope of the surface, and contains shells of marine animals similar to those living in the neighboring ocean.

5. 1. Describe the general form of the district in 3 1. 2. What is the origin of the gently sloping plain? (*DE*, 145.2; *DP*, 119.9; *G*, 151.8; *T*, 72.7.) What statements in § 4 indicate this origin? 3. Which part of the plain first rose above the sea? 4. What is the present altitude of the former shore line? the breadth of the plain? the slope (or *fall*) of the plain in a mile? the direction of the slope (north is at the top of the map)? 5. Print carefully on

the proper parts of 3 1 the words : COASTAL PLAIN, OLDLAND, OCEAN, [FORMER SHORE LINE, NEW SHORE LINE]. 6. Draw in 3 2 a horizontal line showing the sea level as it formerly appeared. 7. What was then the altitude of *A*? of *G*? the depth of *F*? of *L*? 8. How great an uplift of the land with respect to the sea has taken place in laying bare the coastal plain of 3 1? 9. What would have been the breadth of the plain if the uplift had been 150′ (see 3 2)? 300′? 10. Make a general statement showing the relation between the amount of uplift along the border of a continent and the breadth of the resulting coastal plain. [11. Expand this statement so as to include also the effect of greater or less slope of the sea bottom before uplift.] 12. What can you say as to the cause of such regional "uplifts" as are here considered? (*DE*, 158.4; *DP*, 132.2.) NOTE : It is important to remember that such movements of the earth's crust as are here considered take place very slowly, and require thousands and thousands of years.

6. 1. Imagine that the region of 3 1 had not been uplifted, and that you stood at *G*. The view before you might then have been described as follows : "I see a rather steep hillside sloping southward to the seashore, which extends about east and west." 2. If you were at *G* after the uplift of the region, how would you describe the view? [3. Examine 4 7 of the next exercise. What is its contour interval? 4. In what direction does its coastal plain slope? 5. How wide is it at the E. end of the map? at the W. end? 6. What is the greatest altitude of the oldland there shown? 7. What is the altitude of the former shore line at the E. end of the map? at the W. end? 8. In which part of this plain was the uplift greatest? 9. Why does the breadth of the plain vary? 10. What would be its probable breadth 30 mi. farther E.? 30 mi. farther W.? 11. In which direction, and how far, would you have to go to find the breadth of the plain reduced to nothing? Explain.]

7. 1. Describe the forms shown in 4 8, using the terms that you have printed on 3 1. NOTE: 4 8 is from a photograph of a narrow coastal plain (looking NE.) in a bay on the W. coast of

Scotland; it shows the natural appearance of a small example of such forms as are drawn in the outline maps and diagrams of this exercise. 2. The inner border of this coastal plain is 25′ above sea level. How much elevation of the land (or depression of the sea) must have taken place when the plain was laid bare? [3. Draw a map, in hachures or contours, of the district shown in 4 8. (Assume such heights and distances as seem appropriate, and choose your own scale for the map.)] [4. Examine 6 15. What part of what state is there shown? What ocean bounds it on the W.? 5. Locate it on Plate 40. NOTE: The map, 6 15, is copied from parts of two contour maps published by the United States Geological Survey in Washington, D.C. It exhibits the natural irregularities of the oldland hills and the coastal-plain rivers which are shown in simplified form in these exercises. 6. From what original maps is 6 15 taken? 7. What is its scale? its contour interval? 8. What length of the coastal plain is there shown? what breadth? what is the altitude of its inner border? the average slope (feet per mile) to the sea? the direction of the slope? 9. How many streams run from the oldland toward the ocean? NOTE: Several streams cannot reach the ocean directly, because of a long sand reef that has been formed along part of the shore by the sea waves and currents. 10. Mark a point (×) on the oldland from which you could get a good view of the plain. What is the altitude of the point? its distance from the inner border of the plain? from the ocean? 11. Describe the view from this point, looking W., NW., and SW.]

8. [1. The lowering of lake waters may produce a lacustrine coastal plain, similar in many respects to the marine coastal plains thus far described. Explain. 2. The land next S. of lake Erie presents an example of a lacustrine coastal plain, part of which is shown in 35 1. 3. In what state does this example occur? Locate it on Plate 40. 4. The base of the gently sloping oldland is at an altitude of (about) 790′; shade the oldland lightly (in pencil). 5. How broad is the plain? What is its average fall in feet per

mile? (Do not include the fall of the shore-line cliff.)] [6. Draw on a scale of 10 mi. to an inch, with 50′ contour interval, a contour map of part of a coastal plain, about 25 mi. wide, sloping a little N. of E., with the former shore line at (about) 250′ altitude and the oldland reaching 650′, 5 or 6 mi. W. of the former shore line. 7. What is the average fall of the coastal plain? of the oldland?] [8. The illustration below represents a model which shows a district bordering on the sea. What features, there represented, have been studied in this exercise?]

9. Define the following terms: § 2, contour line, contour interval; § 3, profile; § 4, stratum, strata; § 5, coastal plain, oldland; [§ 8, lacustrine coastal plain].

EXERCISE III. VALLEYS IN A COASTAL PLAIN

OBJECT. **To learn the forms produced in coastal plains by rivers and streams.**

Preliminary. If a coastal plain, like the one shown in 3 1 of the preceding exercise, were followed for a few miles parallel to the shore line, a river might be found flowing from a deep valley in the oldland and crossing the plain in a shallow valley to the sea. 4 1 is a block diagram (bird's-eye view) of such a river crossing a narrow coastal plain. (The NW. and SE. corners of the block are cut off to save space.) Level lines, like contours, are drawn on the plain, slanting lines on the oldland and on the valley side. The numbered lines show the altitude of different parts of the plain, valley, and oldland. The heights are much exaggerated compared to the horizontal distances. The smooth valley floor may be covered with water when the river is in flood, and hence may be called the *river flood plain*. NOTE: The more natural appearance of part of such a plain and valley is shown in 4 1*a*: here the upland is divided into cultivated fields, and the valley side is covered with trees. This exercise uses 4, 5, 6, 1–15 (and 3 6); [also 35 1–4].

1. 1. Which is higher, the coastal plain or the flood plain in 4 1? How much higher at *G*? at *H*? at *F*? 2. What is the height interval between the numbered contour lines? 3. Look at the 10′ contour line at *G*. Does it turn N. or S. in passing from the E. part of the coastal plain to the E. side of the valley? 4. Why does it turn in this way? 5. How does it turn at *H* from the valley side to the valley floor? 6. How do you suppose it turns from the valley floor to the W. valley side? from the W. valley side to the W. part of the plain at *K*? 7. Complete the 20′ contour on the E. valley side.

2. 1. 4 2 is a map of the same coastal plain. The top and bottom of the valley sides are marked with dotted lines. 2. Complete the 10′ and 20′ contours on the W. side of the valley; draw some hachures on the valley side; draw the 15′ and 25′ contours. 3. Notice that the contours bend as they pass from the plain to the valley sides. Compare the direction of this contour bend with the direction of slope of the plain; with the direction of river flow. 4. Notice that the contours make a loop in crossing the valley. Is the loop open upstream or downstream? 5. Does the space within the loop become wider upstream or downstream? [6. Why?] 7. What is the altitude of the plain at *C*? at *D*? of the valley floor at *E*? at *F*? 8. What point on the river is at the same altitude as point *K* (or *G*) on the plain? as point *B*? 9. What points on the plain are of (about) the same altitude as *F* on the river? as *E*? 10. How deep below the coastal plain is the valley floor at *E*? at *F*? 11. If a village were at *F*, its people might speak of the neighboring coastal plain as "the upland." Why? [12. Describe the view from *A*, looking W.; looking SW.; from *B*, looking E.; looking N.]

3. 1. Compare the direction in which the plain slopes with the general direction in which the river flows. 2. What reason can you give for thinking that the direction of river flow is a consequence of (or is *consequent* upon) the slope of the plain? NOTE: Rivers whose general course has been determined by the original (or initial) slope of the land, as given by uplift, may be classed as *consequent rivers;* the valleys of such rivers may be classed as *consequent valleys.* 3. 4 3 is a profile across the plain from the oldland to the sea. The broken line *L′R′F′* indicates parts of the river (and valley floor) of 4 2 (or 4 1). 4. Complete the broken line by a [blue] line, and prolong it to the sea. 5. Why is the valley deeper at *F′* than at *E′*? 6. How do you suppose the valley was formed? 7. What controls the depth to which the valley can be eroded? (*DE*, 145.8, 254.1–7; *DP*, 120.5; *T*, 55.8.) (Use the term *baselevel* in your answer.) 8. How is the baselevel of the plain indicated in 4 3? 9. Was the valley formerly deeper or less deep than now? 10. Can

the depth of the valley be much more increased at E'? at L'? 11. What is the average fall per mile of the oldland slope? of the coastal plain? of the river from F to the sea? 12. Which is the steepest? least steep? Why? NOTE: Most coastal plains are much broader than those here shown; the slope of their surface toward the ocean is often extremely gentle and may be less regular than it is indicated in the diagrams of this exercise. 13. What effect would this have on the straightness or crookedness of consequent rivers across such plains? 14. To what class do the streams on the coastal plain of 6 15 belong? 15. Is their direction of flow as regular as that of the stream in 4 2? Explain.

4. [1. What reason can be found in 4 1 or 4 2 for saying, "The river has (practically) ceased deepening its valley from F to the ocean"? in 4 2 (or 6 14) for saying, "The river is still (actively) deepening its valley in the part upstream from F"? 2. Why has the river not worn down its course between F and the ocean to a gentler slope, and thus given that part of its valley a greater depth? [The following questions, 3–8, will aid in answering the preceding one. 3. If a river has no slope, what velocity can it have? 4. If it has no velocity, how much rainfall can it discharge from its drainage basin, and how much land waste (gravel, sand, silt) can it sweep along or transport? 5. The river here considered may have headwaters like those of 1 1. Will it or will it not have some rainfall to discharge, and some load to transport in its lower course? 6. Must it then still have some slope near its mouth? 7. Explain the statements: "When a river has a greater velocity than is needed in transporting its load of waste, it will erode its bed (valley bottom) and thus lessen its slope and decrease its velocity"; "A river cannot erode its bed to so small a slope as to lose the velocity needed in transporting its load of waste." 8. To what parts of 4 2 do these statements apply?] 9. How can the term *graded river* be used in this connection? (*DE*, 254.1; *DP*, 237.6; *T*, 56.9.) 10. Which parts of the river in 4 2 are already graded? not yet graded? 11. Answer the same questions (as well as you can) for the rivers V and Y, 1 1.]

5. [1. When the valley sides are examined closely near the inner border of a coastal plain, such as is shown in the small block diagram, 6 14 (larger scale than 4 1), the hard rocks of the oldland are seen to extend a moderate distance down the valley, under the overlapping layers, or *strata*, of the coastal plain. 2. Draw a [red] line on the valley side of 6 14 separating the coastal-plain strata from the underlying extension of the oldland rocks. 3. Is this line horizontal or sloping? 4. Compare its slope with the slope of the river; of the coastal plain. NOTE: The underground extension of the oldland rocks usually has a surface of much less slope than is here shown. 5. Draw broken [red] lines along the valley side to show the edges, or *outcrops*, of the coastal-plain strata there exposed. 6. Do the coastal-plain strata slope toward the oldland or toward the ocean? 7. Does their total thickness increase toward the oldland or toward the ocean? 8. Can the *structure* (arrangement and composition of layers, etc.) of a coastal plain be better studied in a district without valleys, like 3 1 of Exercise II, or along the valley sides of a district like that of 4 2 (or 6 14) of this exercise? Why? 9. What is the structure of a coastal plain? 10. What is the relation of the uppermost layer to the original surface of the plain? 11. Draw in 6 14 some [red] hachure lines on the E. side of the valley at *A*, *B*, and *C*. 12. Which ones of these lines have a steeper slope near the bottom than near the top? Why? 13. Why is the valley so much narrower and less deep at *A* than at *B*? 14. In 4 3 what is the average fall per mile of the river from *F'* to the mouth? from *L'* to *F'*? 15. Which part is steeper? Why? 16. In which part do cascades and rapids occur? 17. Which part could be most easily followed by boats? 18. Suppose that all the rivers which cross this coastal plain are like the river of 4 2, and imagine a line drawn through all the points having a position similar to *R*. 19. Will this line lie near the inner or the outer border of the plain? 20. Why may it be called the *fall line?* (*DE*, 157.1; *DP*, 127.8; *G*, 70.8; *T*, 75.1.) 21. What is the relative direction of the fall line and the shore line?

22. How is the fall line related to the "head of navigation" (the point farthest upstream which can be reached by boats from the sea)? to the situation of villages or cities that make use of water power in manufacturing? 23. Name several cities of this kind in the eastern United States. (*DE*, 158.2; *DP*, 128.9; *T*, 75.6.) [24. Examine Rocky river, 35.1, near Berea. At what point does it show a rapid fall? What is the (probable) origin of this fall? What use may be made of it in Berea? 25. What evidence does the river give of being graded from the fall to lake Erie? What is its slope in its graded course? How much does it fall at Berea? 26. Compare the depth of the valley beneath the plain, upstream and downstream from the fall; explain the difference.]

6. If § 5 is omitted, omit § 6 also. [1. Suppose that a deep well at *D*, 4 2, reaches hard rocks, like those of the oldland, at a depth of 25′; a well at *C* reaches them at 35′; one at *M*, at 50′ below the surface of the plain. 2. What does this indicate as to the general slope of the ancient sea bottom on which the coastal-plain strata were laid down? 3. Draw a (gently undulating) line in 4 3 to represent the profile of the ancient sea bottom. 4. At what depth below the surface of the plain at *K*, 4 2, would the hard rocks probably be reached in a well? 5. How are the hard rocks of the oldland and the strata of the coastal plain represented on the W. and S. faces of the block diagram, 6 14? 6. Why are the coastal-plain strata drawn slanting on the left side of the block and horizontal on the front face? 7. What facts, observed on the valley sides, or discovered in deep wells, give reason for shading the block faces in this way? 8. State the relation of the facts presented in this section to *artesian wells*. (*DE*, 238.1; *DP*, 126.8; *G*, 154.3; *T*, 72.9.) NOTE: The relation of artesian wells to the Atlantic coastal plain of the United States is fully treated by N. H. Darton, *Bulletin 138, U. S. G. S.*]

7. 1. Mark the river [red] where it is flowing against the valley sides in 4 1? in 4 1 *a*? in 4 2? in 5 8? 2. At such places the base of the valley side is worn away by the river, and as a result the

loose waste on the valley side slips down into the river and is washed away. 3. What effect will this have on the width of the valley floor? Explain by the left slope of 4 4. (This figure is a cross profile of a valley; it is on a larger scale than 4 2.) 4. Where is the waste from the valley sides finally deposited? 5. The river slowly changes its course, now undercutting this part, now that part, of the valley sides. What effect will this have on the width of the valley as a whole? 6. Was the valley formerly narrower or wider than now? 7. What relation must exist between the altitude of the plain (as determined by amount of uplift) and the depth of its valleys? between the age of the plain (time since its slow uplift) and the width of its valleys? 8. Mark × on 5 8 and on 4 1, where cities might be built on the upland close to the river, so as to have the advantage of trade by river boats, and to avoid the danger of river floods. 9. What cities are thus situated with respect to the Mississippi river? (See 5 8*a*, 5 8*b*.) On which side of the river and in what states are these cities?

8. 1. Draw in 4 5 an E.–W. profile across the valley of 4 2 at *DFD'*. (Determine the altitude of the plain and of the valley floor on the line *DFD'* in 4 2; mark on edge of paper slip the breadth of valley at top and at bottom of the side slopes; transfer to 4 5.) 2. Add dotted lines to 4 5 to show two earlier cross profiles and two later cross profiles. 3. Which will be greater in future, the deepening or the widening of the valley? Why? 4. Part of a similar valley is mapped in 3 6*d*: the valley sides are shaded with down-slope lines or hachures; the unworn upland is dotted. 5. Complete 3 6*c* and 3 6*e*, to show earlier and later stages of valley form; complete the other figures of this series. 6. What does the series show as to change in curvature of river? in breadth of valley floor? in upland area? 7. On which is erosion more rapid, a steep valley side or a nearly level upland plain? Why? 8. A valley in the stage of development shown in 3 6*a* may be called *young;* in the stage of 3 6*d*, *mature*. 9. Why are these terms appropriate? 10. In what stage of development is the valley of 4 2 at *H*? 11. The upland

plain bordering the valley of 3 6*d* has been very little changed; such a plain may therefore be described as in a *young* stage of development, although its river and valley are mature. 12. In what stage is the plain mapped in 4 7? 13. In what stage are the valleys of 4 7? 14. What are the most important elements or parts of a young coastal plain? of a mature valley in a young coastal plain? [15. What are the variable elements of a young coastal plain? NOTE: The form of the oldland may vary greatly in different examples; it is sometimes less, sometimes more hilly or mountainous; its border may be nearly straight, moderately curved, or very irregular, etc.]

9. 1. Heavy rain may wear channels or *gulleys* in valley sides. Why? 2. What becomes of the waste that is washed from the gulleys? 3. As time passes, the gulleys are worn back farther and farther into the plain. Why? 4. As the gulleys grow to a length of a few hundred feet or more, they may be called *ravines*. 5. How many ravines are shown in the block diagram, 5 8? (Scale much larger than in 4 1.) 6. Draw in 5 8 [red] lines along the 100′ and 150′ contours on the farther side of the valley. 7. Why do the contours turn from the valley side into the ravine? 8. How do the contours turn where they cross the ravine stream (or rivulet)? 9. 5 9 is a map (on still a larger scale). Which part of 5 8 does it show? Draw the 100′ and 150′ contours in the ravine. 10. How do the contour lines of a main-valley side turn when they come to a side ravine?

10. 1. 5 10, 5 11, 5 12, are contour-line maps (except that ravine *H* is hachured) representing three stages in the development of a valley and its ravines in a coastal plain; the scale is the same as in 4 2. The top and bottom of the valley-side slopes are shown by dotted lines. 2. What is the contour interval? the altitude of the upland and the depth of the main valley at the N. border of 5 10? the breadth of the main valley floor? 3. How can you tell which figure represents the earliest of the three stages? the latest of the three? 4. Draw the stream for ravine *R*, 5 10; draw the contours

for ravine *Q*. 5. How does ravine *T* differ from ravine *R* as to length? as to branches (or forks)? 6. Add a line on the left side of the valley in 4 4 to show the profile of a short ravine stream. 7. Which has the steeper fall, a ravine stream or the river that it flows into? Why? 8. Compare ravine *T* in 5 10, 5 11, and 5 12 as to length; as to branches. 9. How are the changes produced? 10. Compare the direction in which the ravine is lengthened with the direction of its stream flow. Explain. 11. How can the term *headward erosion* [or *retrogressive erosion*] be used in this connection? 12. As the ravines gain the length of a mile or two they may be called *side valleys;* the parts of the upland that enter between ravine or valley branches may be called *spurs*. 13. By what letter are some of the spurs E. of the main valley indicated in 5 11 and 5 12? Print the same letter on four other spurs. 14. In which figure are upland spurs most numerous? Why? 15. Draw in 5 11 and 5 12 the contours for ravine *Q*, beginning with the 50′ contour. Draw the stream (and its branches) for ravine *R*. 16. Add to the left side of 4 4 two side-stream profiles later than the one previously drawn; on the latest profile draw also the profile of a branching rivulet. 17. Which valley, 5 10, 5 11, or 5 12, most nearly corresponds in stage of development to the valley of Rocky river, 35 1. [18. Many of the side streams and valleys in 5 12 are somewhat irregular in direction, but most of the larger ones (almost) agree in direction with the general slope of the plain. Why do they thus (almost) agree? 19. To what class do they belong? (See § 3 of this exercise.) Why? 20. The streams and valleys whose direction is less regular may be called *insequent*, because they do *not follow* the general slope of the plain. Print IN near some insequent ravines in 5 12. 21. The fainter the initial slope of the plain the more numerous and irregular will be the insequent streams. Why?]

11. 1. What is the width of the main valley floor in 5 10, 5 11, and 5 12? What change is shown? How has it been produced? [2. Why has the depth of the main valley not changed? 3. In what direction (compared to the general direction of the river) has

the bend *W* in the main river shifted its position in the change from 5 10 to 5 11? from 5 11 to 5 12? 4. Have the other bends shifted in the same way?] 5. Why may the river and valley of 5 11 be called *mature?* 6. Suppose that the next river valley E. of 5 12 to be a mile away; describe the features that you would pass in walking from one river to the other. 7. Which parts of the upland plain might be described as *dissected* by ravines? Which part as *undissected*, or as *not yet dissected?* 8. What becomes of the rain which falls on the undissected parts? 9. In which of these parts would roads be straight? crooked? Why? In which parts would plowing and reaping be easiest? Why? 10. Which parts would probably be cultivated? Which parts left to be overgrown with bushes and trees? 11. Which parts of a coastal plain (in relation to its main consequent rivers) will be earliest dissected? latest dissected? 12. Upon what factors will the depth of dissection (strength of relief) depend? 13. When so many branching side valleys have been formed that little of the plain remains undissected, why may it be described as *maturely dissected*, or as having reached a *mature stage* in its cycle of erosion? 14. Which reaches maturity first, the upland of a coastal plain or a large consequent river which crosses it? Why? 15. Why may the upland surface of a young coastal plain be described as *undivided*, or as *indistinctly divided* as to stream basins? 16. Why may the upland surface of a mature coastal plain be described as *thoroughly subdivided* as to stream basins? [17. Describe the appearance of a district 80 mi. inland in a mature coastal plain in which the initial surface had a seaward slope of 5′ in a mile, this district extending between two large consequent rivers, 10 mi. apart, each having a fall of 6″ in a mile. 18. What changes in relief would be noted in crossing this district from one of the rivers to the other? in going from the middle of the district to the seashore?]

12. 1. In what direction does the coastal plain of 6 13 slope? About how wide is it? About how high along its inner border? What is its slope in feet per mile? [2. Draw in 6 13*a* a cross profile of

this plain, and indicate the extension of the oldland rocks beneath the strata of the plain.] 3. How many consequent rivers cross the plain from the oldland? 4. What is their average fall per mile? 5. Draw several branching streams, as indicated by the contour lines. [6. Are the branch streams mostly consequent or insequent?] 7. Mark S on some spurs between the stream valleys. 8. Is this plain in an earlier or a later stage of development than the plain of 4 7? How can you tell? 9. In what stage is each plain? State your answers in such terms as early youth, late youth, early maturity, full maturity, late maturity. 10. Suppose the region of 6 13 to be lowered, or depressed, 110′; draw a [blue] line to show the shore line after depression. 11. Why is the new shore line irregular? 12. What is the relation of valleys and spurs of the plain before depression to bays and land-points of the shore line after depression? 13. Why do some bays reach farther inland than others? 14. Why may these narrow bays be described as *partly drowned valleys?* 15. Why may the shore line be described as *embayed?* 16. Would the water in the bays be salt or *brackish?* NOTE: At the head of a long narrow bay, into which a large river flows, the water may be partly salt or brackish. 17. Narrow bays of this kind are sometimes called "rivers." How do such "rivers" differ from ordinary rivers? 18. May the name "river" be properly given to the water that occupies a (partly) drowned valley? [19. Suppose the region of 5 12 to be depressed 75′; draw the new shore line [blue], and shade lightly [blue] the submerged or *drowned* parts. 20. About how deep would the chief bay be at *Y*?] [21. If an explorer came upon a coastal plain, what features should he examine in order to give a good account of it?]

13. [1. Part of the Atlantic coastal plain of the Eastern United States is shown in 35 2. Locate it on Plate 40. 2. What is the scale of the map? the contour interval? the altitude of the upland above sea level? the depth of Trent river valley below the upland plain? 3. This part of the plain is 25 mi. inland from (W. of) the Atlantic shore line. What is the average slope of the plain? the

average fall of Trent river (distance along river course to mouth about 38 mi.)? 4. With which figure of 3 6*a*–6*g* does the Trent valley best correspond? 5. In what stage of development is this valley? 6. Is the plain much dissected or little dissected? In what stage of development is the plain? 7. Another part of the Atlantic coastal plain in North Carolina is shown in 35 3. What is the scale? the contour interval? 8. What is the general altitude of the upland above sea level? the general depth of the valleys below the upland? 9. About how wide are the valley floors or flood plains? 10. What features of this district show it to be in a more or less advanced stage of development than the preceding example? 11. In what stage of development are the streams and valleys? the uplands? 12. A third part of the Atlantic coastal plain is shown in 35 4. Locate it. What is the scale of the map? the contour interval? 13. What is the general altitude of the uplands? the depth of the valleys? 14. In what stage of development is this part of the coastal plain? 15. What movement (elevation or depression) appears to have taken place since the dissection of the plain? 16. How wide is Wicómico "river"? 17. How do you suppose it gained so great a width? 18. Do you think that the water of this "river" is fresh, salt, or brackish? 19. Is the Wicómico properly a river or a narrow bay? 20. Compare the location of the villages, Wicómico and Chaptico.

14. Define the following terms: Preliminary §, flood plain; § 3, consequent river, consequent valley, baselevel; [§ 4, graded river; § 5, outcrop, structure, fall line; § 6, artesian well;] § 8, young valley, mature valley, young coastal plain; § 9, gulley, ravine; § 10, side valleys, headward erosion [retrogressive erosion], spur, [insequent stream]; § 11, late mature valley, dissected plain, maturely dissected plain; § 12, drowned valley, embayed shore line.

EXERCISE IV. PLATEAUS AND CANYONS

OBJECT. **To study the forms produced by the erosion of a plateau.**

Preliminary. 7 1 is drawn as if a block of the earth's crust had been cut out from a plateau, through which a river flows at the bottom of a *canyon*, or deep and narrow valley. The block shows a vertical front face, as *MNRQ*. The figure is drawn as if in a desert, free from vegetation, so as to show its forms better. Horizontal and vertical scales are the same. North is toward the back of the block; the back is (about) two miles from the front. The base of the block represents sea level. Distances E. and W. (right and left) may be measured on the scale of miles at the front base of the block; altitudes, on the vertical scales (broken lines) that rise through the river in the foreground and background. The left front profile is omitted, so that it may be drawn by the pupil. The plateau must be thought of as extending a long distance in all directions. The beginning of the canyon is many miles N.; the end, many miles S. of the part here drawn. This exercise uses 7, 8, 9, 10, 1–10; [also 36 1–5].

1. 1. How many vertical rock faces or *cliffs* are seen in 7 1 on the E. side of the canyon? on the W. side? 2. How many inclined slopes on each side? 3. Compare the cliffs on the two sides as to height; compare the slopes on the two sides as to down-slope length. 4. What is the altitude (above sea level) of the top of cliff *D* in the foreground (use the foreground vertical scale)? in the background (use the background vertical scale)? of the top of cliff *B* in the foreground and background? 5. Where on the W. side of the canyon do you see a group of rock layers, or strata, corresponding to the group which appears or *outcrops* in cliff *D* on the E. side? in cliff *B*? 6. Compare the altitude of the corresponding

cliff tops on the two sides of the canyon. [Make a rough imitation of a plateau and canyon with two piles of books.] 7. Are the strata of cliff *D* in a horizontal or a slanting (inclined) attitude? of cliff *B*? 8. Draw some light lines on the front face of 7 1 to show the attitude of the slope-making strata. 9. Describe the structure (arrangement and composition of the strata) of the plateau. (*DE*, 162.8; *DP*, 141.2; *G*, 175.2; *T*, 82.9.)

2. 1. Suppose that, at time of rain, a small stream ran forward past *X*, 7 1, to the rim of the plateau and fell from the cliff; draw a [blue] line to show its path down to the river. 2. Compare this line with the profile of the E. canyon wall on the front face of the block. 3. What is the (vertical) thickness of the group of strata, or *formation*, which determine cliff *D*? cliff *B*? slope *C*? NOTE: Weak strata crumble away, forming slopes; strong or resistant strata preserve steep cliff faces for a long time. 4. Complete the front profile on the W. side of the canyon (making it correspond to the E. side); shade lightly [or tint with crayons] the strong formations, or cliff makers, for an inch or more to the left of the W. profile. 5. Print letters on the cliff-making and slope-making formations, in the front section, E. and W. of the canyon, corresponding to the letters *A*–*D* on the canyon wall. 6. What is the relation between the height of a cliff face (from bottom to top) and the thickness of the cliff-making formation? between the length of a slope (measured along its incline) and the vertical thickness of its weak formation? 7. Is the uppermost formation *E* strong or weak?

3. 1. What is the general altitude of the plateau surface in 7 1? 2. Fossils of marine animals are often found in the strata of which plateaus, such as the one here figured, are built. Under what conditions must such strata have been deposited? 3. What movement of the earth's crust must be supposed in the plateau region, since the strata were deposited? 4. What is the depth of the canyon beneath the plateau surface at the back of 7 1? at the front? 5. Which way does the river flow? 6. On what formation is the river flowing in the background? In what formation is it flowing

for most of its length in 7 1? 7. To what parts of 7 1 do the rapids, falls, and lower course of the river in 7 1*a* correspond? 8. Draw in 7 1*a* the profile of the rapids and falls when the cliff of the falls stood 1000′ farther S. (use the horizontal scale of 7 1); when the cliff comes to stand 500′ farther N. 9. Describe how the *retreat* or *recession* of the falls is brought about. (*DE*, 251.8; *DP*, 144.2, 235.8; *G*, 41.2; *T*, 54.2.) 10. How do you suppose the canyon was formed? (*DE*, 162.7; *DP*, 141.9; *G*, 32.1; *T*, 81.4.) 11. What is the width of the river? of the canyon at the level of the river in the foreground? of the canyon at the level of the plateau (top of cliff *D*) in the foreground? 12. Why is the canyon wider at the top than at the bottom? 13. Draw two vertical lines in the front of 7 1 to show the form that the canyon would have had if the strata in its walls had not weathered and crumbled (that is, as if the canyon had been cut only by the river). 14. In the canyon as drawn in 7 1, has the greater amount of rock been eroded by the direct action of the river or by the action of weather on the walls?

4. 1. What effect will the (relatively) rapid weathering and wasting of formation *C*, 7 1, have on its sloping face? on the face of the slow-weathering cliff *D*? Answer the same questions for formations *A* and *B*. 2. How may the term *retreat* or *recession* be used in this connection? 3. Draw a line W. of the canyon, showing the profile of its wall after cliff *D* has retreated 200′. 4. What becomes of the large rock blocks that, from time to time, may be loosened by the weathering of cliff *D*? 5. Why is not the bottom of the canyon heavily filled with waste that has fallen from its walls? 6. What relation must exist between the supply of waste from the walls and the load of waste that the river can transport? 7. In order to wash away or transport the waste that falls from the canyon walls, must the river have a rapid or a slow current? a strong or faint slope? NOTE: Some of the waste from each cliff remains on the slope below it, and (with the finer waste from the slope-making formation) makes a cover or *talus* on the slope. Weathering causes the talus fragments to creep slowly down the

slope; washing hastens their movement. 8. What becomes of the talus waste in 7 1 when it reaches the foot of slope *C*? of slope *A*? 9. Which parts of the walls show the greatest amount of bare rock outcrops? Which parts, the least? Why? 10. Do the weak or strong formations show the best outcrops?

5. 1. How does the cross profile of the canyon in the background of 7 1 differ in depth and width from the cross profile in the foreground? 2. Draw in the background (see dotted line *U'U*) a cross profile, as if to show the canyon some miles upstream; another cross profile (see dotted line *V'V*) still farther upstream. How do the depth and width of the canyon change, as it is followed upstream? 3. What will be the position of the river, still farther upstream, in relation to formation *D*? 4. Draw a profile along that part of the river to show this relation (part of formation *D* on the left front face of 7 1 may be used in drawing this profile). 5. In the background of 7 1 draw a profile across the river beyond (N. of) the point where it falls from formation *D*. 6. How is that part of the river course related to the plateau surface? 7. Why do the strong (or resistant) formations deserve the name of "cliff makers" in relation to the canyon walls, and "fall makers" in relation to the river course? 8. In which kind of formation, strong or weak (resistant or yielding), does the greater part of the river course lie? 9. In which kind of formation has the river course a gentle fall? a steep fall? [10. Estimate the fall of the river (feet per mile) from the foot of the *B* falls to the foreground.]

6. 1. Suppose you were at *Q*, 7 1, and wished to go to *M* without descending into and climbing out of the canyon; describe the route you might follow. 2. Draw in the foreground a cross profile (see dotted line *W*, E. of canyon) of the canyon for a point some miles downstream (assuming the altitude of the plateau to continue unchanged). 3. How does profile *W* differ in depth and width from the foreground profile of 7 1? How does profile *W* differ from profile *V*? 4. How do the depth and width of a canyon vary as it is followed downstream? Explain. [5. What limits the depth to

which a canyon can be cut? (Consider, in your answer, altitude of plateau, slope of river, and distance from the river mouth.)] 6. What changes in depth and breadth would you expect at the front profile of 7 1 if weathering and river action continued for a long time? Why have these changes not already taken place? 7. Would you describe the river and canyon as young, mature, or old? Why? 8. What stage in the cycle of erosion do you think the plateau has reached? 9. What are the chief characteristics of a young plateau? [10. The Zambezi river in the interior of South Africa (locate the river on Plate 45) flows in a broad channel with a moderate current on a plateau (altitude, 3500′), following a broad and shallow valley for many miles; it then suddenly plunges down 300′ at Victoria Falls into a narrow and steep-walled gorge or canyon, through which it rushes rapidly in a narrow channel. The canyon continues 40 mi.; it deepens and widens (and its side canyons increase in length) as it is followed downstream from the falls. 11. What is the origin of the canyon? of the falls? (See (London) *Geographical Journal*, Vol. XXV, 1905; Vol. XXIX, 1907; excellent plates.)]

7. 1. 8 2 is a diagram of another plateau and canyon drawn in the same way as 7 1. How does it differ from 7 1 as to altitude of plateau? altitude of river in foreground? depth of canyon below plateau surface? breadth of canyon at plateau level? amount of original plateau uplift? number of cliffs and of slopes in canyon wall? height of waterfall in river (near *B*)? 2. Complete the front profile W. of the river in 8 2 and draw lines separating the cliff-making and slope-making formations; shade lightly the cliff-making formations W. of the canyon; print letters on the several formations corresponding to the letters on the canyon wall. 3. Has the plateau mass a horizontal or an inclined structure? 4. Draw two canyon-wall profiles, *W*, *X*, as if for points farther downstream, in the E. foreground; two, *U*, *V*, as if for points farther upstream, in the E. background. 5. Mark ⊙ at a point where you would go to get a good view up the canyon if you were on the E. part of the plateau; ⊙′, on the W. part for a view down the canyon. [6. Do

the dots in these circles represent (about) the size of a man or of a house?] 7. What is the width of the canyon at the level of layer *H* in the foreground? in the background? at the place of greatest width? 8. Why does the width vary? 9. Why does the E. side canyon fork near its head (*Y*), while the W. side canyon does not fork at its head (*Z*)? 10. At what time in its history (earlier or later than now) would the E. side canyon resemble the present form of the W. side canyon? When would the W. side canyon resemble the present form of the E. side canyon? Explain.

8. 1. Why is cliff face *D*, § 2, higher (from bottom to top of cliff) than cliff face *E*? cliff face *F* than *H*? [2. Why is slope *G* less steep than slope *C*?] 3. Why do falls occur in the river near the foreground? 4. If you could follow up the river, would the next fall probably be of greater or of less height than the one here shown? Why? 5. How many falls occur on the (wet-weather) stream of the E. side canyon? of the W. side canyon? Why? (*DE*, 252.2; *DF*, 111.2; *G*, 38.8; *T*, 51.1.) 6. Counting down from the plateau, which fall on the side streams will be the highest? 7. Draw on the W. front face of § 2 a line (beginning at the river) to represent the profile of the W. side stream. 8. Which has the (average) steeper descent, a side stream or the wall of the main canyon? a side stream or the main river? Explain. [9. If you wished to descend from the plateau to the river, where would you try to find a way? Why? In which part of such a way would the greatest difficulty be found? Why?] [10. Draw (short) horizontal lines to separate the strong and weak formations corresponding to the profiles in § 2*b* (the *profiles*, which show only the surface, are thus changed into *sections*, which show also the internal structure). Shade (lightly) the cliff makers in one of the sections. 11. Which section has two thick resistant formations? many thin resistant formations? a great thickness of weak strata in its lower part? How can you tell?] [12. The weaker formations are sometimes weathered back a few feet under the overlying cliff-making formation, which therefore "overhangs," forming natural "cliff caves." § 2*a* is a sketch

of such a cave, in which a rough wall has been built to give better protection. Many such "cliff dwellings," now more or less broken down, are known in the canyons of Colorado, New Mexico, and Arizona, but they are no longer occupied by the Indians who formerly (before the coming of the white men) lived in them.]

9. 1. 9 3 shows part of still another plateau and canyon; compare it with 8 2 as to general altitude of the plateau; depth of the canyon; number of cliffs and slopes; width of canyon at plateau level; amount of plateau uplift. 2. In which example, 7 1, 8 2, or 9 3, do you think a longer time has passed since uplift and erosion began? How can you tell? 3. Complete in 9 3 the profile and section on the W. side of the canyon. How far has cliff *J* retreated westward since it was first cut through by the river? 4. Which cliff has retreated the most, *J* or *G*? *G* or *E*? Why? 5. Is the retreat of cliff *E* more affected by the retreat of slope *F* or of slope *D*? Why? 6. Above which cliffs is there a nearly level bench or *platform* (from top of cliff to base of next higher slope)? [7. Explain the origin of the platform over cliff *E*; over cliff *G*. (*DE*, 163.9; *DP*, 143.9.) 8. Why is one of these platforms broader than the other? 9. Why is there no platform over cliff *C*? 10. What becomes of the talus on slope *B*? on slope *D*? on slope *F*? on slope *H*? (*DP*, 144.1.) 11. Draw another W. wall profile, as if the river had worn down its channel 100′ deeper and the main cliff had retreated 500′. 12. About how much additional retreat of the top cliff is thus shown? 13. What change in the width of the platform on *E* is thus shown?

10. [1. The canyon of the Colorado river has been eroded in a plateau; part of it is mapped in 36 1. Locate on Plate 40. A cliff is shown where two or more contours are close together; a platform, by wide-spaced contours. What is the altitude of the plateau? of the river? the depth of the canyon? How far is the plateau rim S. of the river? 2. How many cliffs, slopes, and platforms are shown? 3. Which cliff, counting down from the top, seems to be highest? (See Powell's *Explorations of the Colorado*

River of the West, Washington, 1875; a remarkable narrative of an adventurous journey down the river in boats (see especially p. 100); many plates. Dutton's *Tertiary History of the Grand Canyon District. U. S. G. S., Monogr. II* (see the excellent plates in atlas of this report, especially VI); an abridgment of Dutton's work is given in the *Second Annual Report of the U. S. G. S.* The large contour map, Bright Angel quadrangle, Arizona, by F. E. Matthes (from which the map 36 1 is taken), is an extraordinary example of topographic surveying.)]

11. 1. If you walked along the edge or "rim" of the plateau, 9 3, would your path be straight or irregular? more or less irregular than the course of the river? Why? 2. Why is the edge of the plateau in 8 2 more irregular than that in 7 1? in 9 3 more irregular than in 8 2? 3. Why is the edge of the uppermost cliff *J*, 9 3, more irregular than that of the second cliff *G*, and so on down to cliff *C*? 4. Draw a line (so far as there is room) on the front face of 9 3, beginning at the river, to represent the profile of the E. side-stream. 5. How does this differ from the corresponding profile drawn in 8 2, as to average slope? as to number of falls? [6. In 9 3*b* the formations with odd numbers are resistant cliff makers. Draw profiles of canyon walls corresponding to the several positions of the river, *A*, *B*, *C*, *D* (as if the profiles were in succession farther and farther downstream).] [7. Where in 9 3 is some of the coarser waste from the side canyons deposited? (See 9 3*a*, drawn on a larger scale.) 8. What is the form of these deposits? What name is given to them? (*DE*, 197.4; *DP*, 275.9; *G*, 38.4; *T*, 66.5.) Why are they not seen in 7 1? NOTE: When unusually heavy rains occur, a violent flood may rush down a side canyon and sweep great bowlders into the river; before another flood occurs, the river may gradually roll most of the bowlders downstream. 9. What effect has a "fan" on the width of the river at the fan front? next upstream from the fan? on the slope of the river? on the river current? on the river bank opposite the fan? on the passage of boats or rafts down the river?] [10. Imagine that several rivers, like the

one shown in 9 3, crossed the plateau, 20 to 50 mi. apart; describe the general appearance of the region. 11. Would most of the region be occupied by undissected plateau surface or by canyons? 12. When the cycle of erosion is complete, the plateaus would be worn down to a lowland. Does 9 3 represent an early or a late stage of a complete cycle? 13. May the plateau in 9 3 be described as young, mature, or old? 14. Compare the depth to which the river has eroded its canyon in the plateau with the depth to be eroded in future. 15. Has the river in this part of its course developed a rather evenly graded course, or is it still interrupted by steep waterfalls? NOTE: A river with many waterfalls in a narrow valley might be called *young;* with an evenly graded course but without a flood plain, *early mature;* with an evenly graded course and an open flood plain, *late mature.* 16. In which of these stages is the river in 9 3?]

12. 1. 10 4 is intended to represent a later stage (many thousand years later) in the erosion of the plateau which is shown in 9 3. Complete the W. front section in 10 4 and add letters corresponding to those of 9 3. 2. Compare 9 3 and 10 4 as to altitude of plateau (the plateau surface in 10 4 is seen only in the far right-hand (NE.) corner. Why?); amount of uplift; depth of canyon; altitude of river in foreground. 3. Compare the two figures as to amount of load received by river from canyon walls (the steeper the walls, the more waste falls from them); from side canyons (the longer the side canyons, the more waste they supply); fall of river in feet per mile (length of river here shown in each figure, 2 mi.); width of canyon bottom or floor (from talus to talus); width of canyon at level of plateau. (In 10 4 the width is (about) twice the distance from background vertical scale to back profile of cliff *J* in NE. corner. Why?). 4. Compare the two figures as to length of side canyons; number of cliffs and slopes shown E. of river. Why are fewer cliffs *seen* in 10 4 on W. than on E.? 5. Compare the two figures as to breadth of platforms; average slope of canyon walls (in 10 4, slant of straight line drawn at back of block from top of cliff *J*

to base of lowest talus). 6. Where these comparisons show differences, explain them. 7. In the change from 9 3 to 10 4, why has the widening of the canyon at the top been greater than the deepening at the bottom? [8. Is the retreat of cliff *E* more affected by the weathering of slope *D* or of slope *F*? Why? 9. Which cliff face *tends* to retreat more rapidly, *C* or *E*? Why? 10. Why is cliff face *C* less distinct than *E*? less distinct than *C* in 9 3? 11. Explain the origin of the flat canyon floor in 10 4. How does it differ in origin from the platforms?]

13. 1. If the plateau of 10 4 were seen in a still later stage of erosion, what change would you expect to find in the altitude of the river? in its fall per mile? in the depth of the canyon? in the width of the canyon floor? of the canyon top? 2. What change would you expect in the length of the side canyons? in the breadth of the platforms? in the number of cliffs, slopes, and platforms? in the irregularity of the plateau rim? 3. As the plateau is more and more eroded, will the term *canyon* be more appropriate or less appropriate as a name for its valleys? 4. Estimate (roughly, in miles) the whole length of the E. side canyon of 10 4. 5. Imagine other rivers and canyons like those of 10 4, 20 to 50 mi. apart. Would traveling be easy or difficult along a line about midway between two such rivers? Why? 6. Imagine that the side canyons have increased to lengths of from 12 to 30 mi. What effect would be produced on the plateau where the heads of two side canyons meet? 7. Describe a route of travel under such conditions about midway between two rivers? NOTE: When wide belts of undissected plateau surface remain between the river canyons, the plateau may be called *young;* if the main canyons are very narrow and the side canyons are very short, the plateau is *very young;* as the main canyons widen and the side canyons lengthen, so that the belts of plateau surface are narrowed (but still retain an even surface along the divides between the rivers), the dissection of the plateau may be called *early mature;* when the side canyons of neighboring rivers meet at their heads, the plateau

reaches a *late mature* stage of dissection. 8. In what stage is the plateau of question 5, above? of question 6? of 8 2? of 7 1? In what stage of development is the river of 10 4? (See Note, end of § 11.) Explain. 9. What are the characteristic features of a young plateau? of a late mature plateau? of a very young plateau? of an early mature plateau? [10. 10 4 *b* represents cliff and talus slopes of another plateau in greater detail than 10 4. Draw lines to the left of the profile (in the air) to represent the internal structure that is indicated by the external form; shade lightly the harder formations. 11. Where do some strata of intermediate resistance occur (neither good cliff makers nor good slope makers)?]

14. [1. 7 5 is an outline map of part of a river system in a dissected plateau. How does the scale of this map compare with the scale of 7 1 and 10 4? 2. Let there be only one cliff-making formation in the structure of this plateau, and let the line *aa*, 7 5, represent the edge of the cliff E. of the river in an early stage of dissection. (Neglect the lines *bb*, *cc*, for the present.) 3. Why does the cliff line turn into the plateau (away from the main river) in several sharp angles or reëntrants? turn toward the river in several curves? 4. What is the relation of the reëntrants and curves to the side streams? 5. Why do the reëntrants extend to different distances from the main river? 6. Draw a similar line *a'a'* (beginning at N. end), to show the corresponding cliff W. of the river. 7. The line *bb* may now be taken to show the same cliff at a later stage of erosion. Is the cliff now less or more irregular than before? Why? 8. Draw a corresponding line *b'b'* W. of the river. The side ravines are now long enough to be called side canyons. The line *cc* shows a still later position of the same cliff: what peculiar feature does it show at *R*? 9. How has this part of the plateau surface come to be separated from (or to "lie out" from) the rest of the plateau? Such an isolated part is called an *outlier*. 10. Draw a third cliff line W. of the river, corresponding to *cc*. How many outliers does it show? Explain their origin. 11. Will these outliers increase or decrease in size as erosion continues? Why?

12. Are outliers likely to increase or to decrease in number as erosion progresses? Why?]

15. NOTE: If § 14 is omitted, omit § 15 also. [1. Another use may now be made of 7 5: it may be taken to represent a well-dissected plateau, with three cliff makers, *a*, *b*, *c*, separated by slope makers. 2. Which cliff maker stands highest in the plateau structure? How can you tell? 3. A section along the line *MN*, 7 5, is given in 7 6. Complete, in 7 7, a section along the line *QS*, 7 5. (Measure distances in 7 5 on a strip of paper, from *Q* to cliffs and streams, and transfer the distances to 7 7.) 4. A hachured map of a similar plateau is shown in 7 9. How are the steep cliff faces indicated? the talus slopes? the nearly level plateau surface and the narrow platform over the middle cliff? 5. Draw hachures for the rest of the figure. 6. 7 8 is a contour map of part of a similar dissected plateau. Why are the contours so crowded on the cliff faces? What is the contour interval? 7. What is the altitude of the plateau surface? About how deep is the main canyon? 8. Draw contours for the rest of 7 8. 9. From which figure can you gain the best idea of the plateau forms,—the outline map (7 5), the profiles (7 6 and 7 7), the hachured map (7 9), or the contoured map (7 8)? Why? 10. From which map, 7 5, 7 8, or 7 9, can an accurate cross section be best drawn? Why? 11. Which kind of a map would you prefer in finding your way across a dissected plateau? Why?]

16. [1. Consider a broad plateau hundreds of miles across. What general effect will the branching rivers and [frequently insequent] side streams of a large river system (or of several river systems) have, as time passes, on the form of such a plateau? 2. The line *cccc*, 8 10, shows a profile across part of such a plateau. How many cliff-making formations are represented? How far apart are the two rivers *r*, *r'*? 3. With which one of the plateaus, 7 1 to 10 4, does the profile *cc*, 8 10, most nearly correspond as to stage of erosion? 4. Draw profiles (beginning at the right) for two earlier stages, *b* and *a*, in 8 10; for two later stages, *d* and *e*.

5. When the profile has reached the stage *d*, which part of it represents a *mesa?* in stage *e*, which part represents a *butte?* (*DE*, 171.3; *DP*, 150.6; *G*, 91.9–; *T*, 82.8.) 6. What features occupy the greatest area in stage *e*? What features are most conspicuous in the landscape of stage *e*? 7. Draw profiles for still later stages, *f* and *g*. 8. What has become of the butte (stage *e*) in stage *f*? 9. To what form has the lower cliff maker been reduced in stage *f*? in stage *g*? 10. What feature occupies the greatest area in stage *g*? What is then the most conspicuous feature? 11. Draw a profile for stage *h*. What name might be given to the region in this stage? 12. Describe the general appearance of the district in stage *a*; in stage *e*; in stage *g*; in stage *h*.]

17. NOTE: If § 16 is omitted, omit § 17 also. [1. In which of the various stages, *a* to *h*, § 10, might the district there represented in profile be called a young plateau? an old lowland? a maturely dissected plateau? 2. Explain the altitude of the lowland or peneplain *r'hr* in relation to baselevel? 3. In which stage (young, mature, or old) of erosion of the plateau would its valleys be called canyons? would roads and settlements be found chiefly on the highlands? on the lowlands? 4. In which stage would outliers be common? would the lower cliff maker be reduced to isolated buttes? 5. Where would such buttes stand in relation to the main rivers? 6. How is the term *cycle of erosion* illustrated by § 10? 7. Suppose that when stage *g* had been reached, a general uplift of the region occurred; draw a [red] line in § 10 to show the profile of the district when the stage of youth had been reached in the new cycle of erosion (introduced by the new uplift); when the stage of maturity had been reached in the cycle.]

18. [1. 36 2 represents a plateau dissected by canyons. Locate it on Plate 40. In what part of what state is it? 2. State the scale; the contour interval; the general altitude of the plateau; the depth and breadth of the main canyons; the length of the side canyons. 3. Is the cycle of erosion half accomplished, nearly completed, or only well begun? 4. In what stage of dissection is the plateau?

5. 363 is another part of the same plateau, about 50 mi. NE. of 362; the same river is shown in both figures. 6. In what part of 363 is part of the undissected plateau surface seen? What is its altitude? [7. Can you explain why Purgatoire river flows NE.? To what class does it seem to belong?] 8. Print on 363 PLATEAU, CLIFF, PLATFORM, SIDE CANYON, VALLEY FLOOR, in their proper places. 9. How many cliff-making formations are here exposed? How wide is the platform between the two cliffs? How high is each cliff? How long (about) are the side canyons? How wide is the valley floor? 10. In what stage of dissection is the plateau? 11. Compare the canyon of Purgatoire river in 362 and 363 (in each case measure canyon width from plateau rim). 12. What general rule of canyon form is here illustrated? (See question 4, § 6.) 13. Locate the district shown in 364 on Plate 40. In what part of the Allegheny plateau does it occur? (See *DE*, Fig. 78; *DP*, Fig. 92.) State the scale and contour interval. 14. What is the altitude of the plateau? of the valley floors? the relief of the district? 15. What is the width of the upland belt (between the side-valley heads) E. of Battle Creek valley? How long and wide are the upland spurs (to W.)? Which occupy the greater area, the plateau surfaces or the valleys (from rim to rim of plateaus)? 16. In what stage of dissection is the plateau in this district? (See Note following question 7, § 13.) 17. In what stage of development are the main streams? 18. Where do waterfalls occur? In what stage of development are the upper parts of the side streams? 19. Locate the district shown in 365, on Plate 40. What is the scale? the contour interval? 20. What is the altitude of the valley floor (or flood plain) of Blackford creek? the altitude of the hilltops? the relief of the district? 21. Which occupy the greater area, the hilltops or the valley floors? 22. This region was once an even upland (or plateau of moderate altitude). In what stage of dissection is it now? 23. In what stage of development is Blackford creek? 24 If this creek is here 700′ above sea level, why does it not wear its valley floor down lower? 25. To what

class do the side streams in 36 2–5 apparently belong? (See Exercise III, § 10, question 20.) Why?

19. [1. Locate 9 3*c* and 9 3*d* on Plate 40. In what part of the Allegheny plateau are they? (See *DE*, Fig. 78; *DP*, Fig. 92.) 2. What is the scale of these maps? the contour interval? 3. What river is shown in 9 3*c*? How deep is its valley beneath the neighboring uplands? 4. How wide is the river? the valley floor? 5. Draw a [red] line around the strip of valley floor NW. of the river, and around the strips of valley floor SE. of the river (neglect the valley floor of the branch stream on NE.); a [blue] line where the river touches the base of the steep valley side. 6. As you follow down the river, how are the successive valley-floor strips arranged? 7. Compare the course of Purgatoire river, 36 2, with the course of the Ohio river, 9 3*c*, and of Captina creek, 9 3*d*. Which of these streams might be described as nearly straight? moderately curved (or sinuous)? strongly curved (or serpentine, or *meandering*)? 8. Which of these streams has eroded a meandering valley? (*DE*, 271.7–; *DP*, 253.4; *G*, 51.8; *T*, Fig. 143.) 9. As a meandering valley is widened, is the valley floor normally on the inside or outside of the stream curves? On which side of the stream curve is the steeper valley side? (*DE*, 258.9.) 10. Shade [blue] the normal valley floors and [red] the normal steep valley sides of 9 3*d*. 11. Do any abnormal cases occur? If the stream there followed the broken-line curve, would these cases be normal or abnormal? 12. What change of stream course has probably taken place there? 13. Which meander curve is entered by a spur with a low, narrow neck? 14. Locate 10 4*c* on Plate 40. Of what plateau is it a part? 15. What is the altitude of the plateau in 10 4*c*? the depth and breadth of Cheat river canyon? 16. In what stage of development are the river and its canyon? 17. Are the side canyons long or short? Are their streams of strong or gentle fall? 18. Locate 10 4*d* on Plate 40. In what state is it? What is the altitude of the highest and lowest parts? 19. Begin near the NW. corner and draw a [red] line eastward along the divide between the NE. and the SE. streams. NOTE:

The streams are drawn in broken lines to indicate that they cease flowing in dry weather. 20. Does the divide follow a uniform altitude? 21. All this district was once a plateau of at least 5000′ altitude. To which profile in 8 10 does it now correspond? What stage of dissection has it now reached? 22. How many buttes are shown? Explain their origin. 23. To what features in 10 4 *d* does 10 4 *a* correspond? 24. What is the origin of the plain in 10 4 *a*? To which profile in 8 10 does it correspond? 25. In what stage of the cycle of erosion is the district of the Enchanted Mesa? (*DE*, 172.3; *DP*, 151.5.) 26. In what part of the United States is it? 27. Locate (roughly) on Plate 40 the canyon of Kanawha river, shown in the figure at the bottom of this page. Compare this canyon with the canyon of Cheat river, 10 4 *c*. 28. In what stage of development is the Kanawha canyon?

20. Define: Preliminary §, canyon; § 1, cliff, outcrop, structure; § 2, formation, cliff-making formation, slope-making formation; § 3, retreat or recession of waterfalls; § 4, retreat or recession of cliffs, talus; [§ 8, profiles and sections;] § 9, platform; [§ 11, alluvial fan, young river, early mature river, late mature river; § 13, young plateau, maturely dissected plateau; § 14, outlier; § 16, mesa, butte;] § 17, cycle of erosion; [§ 19, meandering river, meandering valley].

EXERCISE V. THE SCULPTURE OF MOUNTAINS

OBJECT. **To explain various features of mountain ranges.**

Preliminary. 11 1 gives a general view over a rolling district of low hills and shallow valleys, all covered with a deep weathered soil. The district is drained by a large river and many smaller streams, all flowing quietly and smoothly through their flood plains. The soils vary from place to place, as if the underlying rocks were of different kinds. Some low mountains rise in the E. and NW.; there the soil is thinner and more stony. The view is cut off in front by a vertical section, the baseline of which is at sea level. Altitudes are marked at various points; a scale of altitudes is drawn near the NE. corner, and a scale of miles along the front baseline. This exercise uses 11, 12, 14, 13, 16, 1–22 [also 37 1–5]. Note that Plate 14 is to be used before Plate 13.

1. 1. The distance along the winding river *A* to *E*, 11 1, being 30 mi., what is the average fall of the river in feet per mile? 2. If *E* is 600 mi. from the river mouth, what is the average fall from *E* to the sea? 3. What is (about) the width of the main river flood plain? 4. The altitudes on stream (or small river) *F* (SE. corner of 11 1) are indicated for points two miles apart. What is its average fall? the width of its flood plain? 5. Why may the streams of this district be described as "thoroughly graded with respect to their general baselevel" (the ocean)? 6. What is the general altitude of the *interfluves*, or spaces between the small rivers (see foreground profile)? their relief? 7. What is the altitude of the highest mountain on the N. border? the general relief in that mountain group? NOTE: To find (roughly) the height of the mountain above the surrounding district, draw a straight line between the parts of the N. border marked 900′, and measure the mountain height above this line.

2. 1. If you should walk eastward from *W* to *W'*, how many times would you go uphill and downhill? about how many feet would you ascend and descend in each case? 2. Print D at points where you cross divides between the small rivers *J*, *H*, *G*, *F*; print d where you cross subdivides between side streams. 3. Draw a line up and down hill, eastward from *X* to *X'*, and answer the same questions as in question 1. 4. Draw an E.–W. line through *Y* (W. center of figure) and print D where the line crosses the divide between the two streams there shown. 5. Draw similar lines through *Z*, *Z*, *Z*, and mark the divides on them. 6. Draw a broken [red] line southward from *Q*, on the N. border, through *Y* to the S. border of the figure, dividing the drainage area of the main river from that of the W.-flowing rivers. 7. Draw a broken [red] line westward from *M*, on the E. border, to *M'* near main river, dividing the drainage area of the main river *AE* from that of the small rivers *F*, *G*, *H*, *J*. 8. Should the various divides and subdivides that you have marked be described as "high, sharp, and well defined" or as "low, gently rounded, and ill defined"?

3. 1. Draw a line along stream *F* and its NW. branch, over the divide at its head, and down stream *R*; mark D at the divide. NOTE: In 16 15 the small crosses (× ×) represent the altitudes of the two-mile points on streams *F* and *R* of 11 1; and the dots in the small circles represent the altitudes of the low hills on the neighboring interfluves. (The vertical scale in 16 15 is the same as in 11 1; the horizontal scale is smaller.) 2. Draw a line through the crosses; through the dots. What do these lines represent? Print F and R near these lines; draw a short vertical line at the divide between streams *F* and *R*. [3. Suppose the district of 11 1 to be inhabited in this stage of its history; locate a city and some villages in the SE., central, and NW. parts of the district; connect some of them by a railroad (heavy line) and by several roads (light lines). NOTE: The railroad should not have grades of more than 100′ in a mile; the roads seldom more than 500′ in a mile. 4. What are the chief difficulties that would be met in making the

roads and the railroad? 5. Which parts of the district are well adapted to farming? Which parts will probably remain forested while the rest is cultivated? 6. Which parts are liable to overflow by river floods? How much of the main river appears to be navigable for river boats?]

4. 1. 12 2 shows another stage in the history of the same district, uncounted thousands of years later than the stage shown in 11 1. 2. Look at the middle W. part of 12 2. Follow the broken line *O O'O''* from W. to E. and note the altitudes along it; note that this part of the district may be described as "arched" or "upwarped." 3. Begin in the SE. corner of the district and follow the line *NN'*, noting the change of altitude along it. What has happened in this part of the district? 4. Begin at the middle of the E. side, and follow the line *MM'Q'Q* to the N. border; this line may be described as "following the crest of the arch," or the "crest of the upwarping." 5. What directions does the crest line follow? 6. Is the amount of upwarping uniform all along the crest line? 7. Near the head of which stream is it least? NOTE: The upwarping of the surface, as here shown, is much stronger than ordinarily occurs in mountain ranges. The upwarping is exaggerated in these figures, so as to bring well-developed forms into a small district for easy study. The origin of the forces which slowly warp the earth's heavy crust is not well understood, but the great strength and long-continued action of the forces cannot be doubted; they do not seem to be related to volcanic action. 8. In 16 15 the dots in the larger circles represent several points on the line *NN'*, 12 2. Draw a curve through the dots. What does this curve represent? 9. Draw, beneath this curve, the profiles of streams *F* and *R* (see small crosses + +). Print F and R near these profiles; draw a short vertical line at the divide. 10. How many feet beneath the upland is the deepest part of each valley? 11. Why is stream *F* shorter, and why is *R* longer than in the corresponding profiles previously drawn in 16 15? [12. Why may *F* be described as "beheaded by warping"? *R*, as "extended by warping"?] 13. What

is now the average fall of *F*? 14. In so steep a stream there will be many falls and rapids; the water will flow swiftly in a narrow channel, plunging and foaming; at times of flood the rushing stream or *torrent* will sweep along large bowlders. In what stage of development is such a stream?

5. 1. If you went E. along line *WW'*, 12 2, how many times would you go up and down hill? 2. Draw a similar line *XX'*. 3. Stream *G* has three forks,—east, middle, and west; compare profiles *WW'* and *XX'* where they cross the valley of the E. fork of *G*; the W. fork. [4. Draw in 16 7 the cross profile (1) of the W. fork of *G*, on line *WW'* in 12 2; (2) of the small E. branch of *H* on line *XX'*; (3) of *J* on *WW'*; (4) of *F* on *WW'*; (5) of the three forks of *G* on *XX'*; (6) of *H* on *VV'*. 5. How does cross profile (3) differ from (1) and (2); (4) and (5) from (3)? (6) from (4) and (5)?] 6. Why are the valleys of *F*, *G*, *H*, etc., in 12 2 unlike the corresponding valleys in 11 1? 7. Why may the streams of 12 2 be described as *revived* or *rejuvenated*? 8. What has caused their revival? 9. Why may the new valleys be described (in cross profile) as *sharp V-shaped valleys*? 10. Why did not the streams in 11 1 erode sharp V-shaped valleys? 11. Which parts of the valleys in 12 2 most nearly resemble the valleys of 11 1? Why? [12. Compare the steep valley sides in 12 2 with the neighboring uplands, as to depth of soil; as to amount of bare rock ledge exposed.]

6. [1. A small part of the Sierra Nevada mountains is shown in 37 1. Locate this district on Plate 40. In what part of what state is it? What is the scale of the map (miles to an inch)? the contour interval? 2. What is the altitude of the upper valley of Turnback creek? 3. Is the valley floor there narrow or broad? 4. How much higher than this valley floor are the hills 2 mi. to the W.? 5. How deep are the valleys of Tuolumne river and its north fork? Are they broad or narrow floored? Are the valley sides steep or gently inclined? 6. By what sort of a valley is the open upland valley of upper Turnback creek connected with the deep and narrow valley of Tuolumne river? 7. How many other creeks

show similar features? 8. Compare the uplands, the upland hills (or mountains), the deep main valleys, and the side valleys of this district in the Sierra Nevada with corresponding features in 122. 9. Why may Tuolumne river be described as "revived"? 10. Explain the origin of the deep valleys of this district. 11. A small part of the Front range of the Rocky mountains is shown in 372. Locate this district on Plate 40. In what part of what state is it? What is the scale (miles to an inch)? the contour interval? 12. In this part of the Rocky mountains do the highest summits rise in sharp peaks and ridges, or in a broad rolling highland? 13. What is the general altitude of the highland area? 14. How deep are the valleys below the highland? 15. What is the general altitude of the valley floors? 16. Do you think the valleys may be worn much deeper in future? Explain. 17. What is the probable origin of the forms here shown?]

7. 1. In 122 which parts of the main river (indicate by letters *A*, *B*, etc.) flow in steep, rock-walled gorges or canyons? on plains? 2. What is the average fall of the river in the farther gorge (length here shown, 4 mi.)? in the nearer gorge (length, 11 mi.)? on the farther plain (river length, 11 mi.)? on the nearer plain (river length here shown, 4 mi.)? 3. Will the river current be faster or slower in gorge *CD* than in the corresponding part of 111? 4. Compare the breadth of this part of the river in the two figures; explain the difference. 5. In 169 a profile along the main river of 111 is shown (looking E.) by the line *A'E'*; the main river of 122, by *A"E"*. Lay a ruler (or straight edge of sheet of paper) along the part *A"B"*, and compare its slope with that of the other parts. 6. How is the depth of the gorge *CD* indicated in 169? What is the depth in feet? (See the vertical scale in 169.) 7. What relation exists between depth of gorge and amount of upwarping? 8. Where would you go in 122 to get the best view of the deep rock structures that underlie the upwarped uplands? NOTE: The complicated disorder of rock structure in such districts as are here considered is illustrated in the front corner sections of 1613, and (less distinctly) in

the shading of the canyon walls in that figure; see also the front section of 16 20.

8. 1. Why may the dotted area *B–C*, 12 2, be described as a *basin plain?* 2. Where have the layers of gravel and sand, or *alluvial deposits*, which cover this plain, come from? 3. The thickness of these alluvial deposits, determined by deep wells bored at various points, is shown by vertical lines beneath the river profile *B''C''*, 16 9; draw a curve through the lower end of these vertical lines. 4. What does this curve represent? Compare it with the curve *C''D''* in the same figure. 5. Why may the inclosed district occupied by the basin plain be described as having been bent down, or *down-warped?* 6. Why have layers of gravel and sand been deposited in the down-warped area? What is their greatest total thickness? [7. What mountains inclose the great plain of the "valley of California" on the E. and W.? (*DE*, 265.4, 267.2; *DP*, 288.5, 291.1–; *G*, 161.1; *T*, 68.2.) 8. The mountain valleys decrease in depth toward the great plain; there the streams flow out on nearly flat alluvial fans, which unite to form the great alluvial plain of the "valley" (over 300 mi. long, about 50 mi. wide). 9. Point out similar features in 12 2. 10. What is the probable origin of the "valley of California"? 11. By what two chief rivers is it drained? Through what "drowned valley" (or bay) do the river waters reach the Pacific ocean?]

9. 1. If the warping in the region of 11 1 had taken place very rapidly, and raised the high-crested barrier *MM'Q'Q*, 12 2, across the main river course, and the river had been stopped for a time, where would a large lake have been formed? 2. Where would the rising waters of such a lake have found an outlet? Why? (The upwarping of the region NE. of the district here shown is supposed to be higher than the line *MM'Q'Q*.) 3. There is no sign of a lake (except the small oxbow lakes, made by the river) in the basin plain; and the gorge *CD* has been eroded along the course that the river followed previous to (or *antecedent* to) the warping. 4. Then what must be concluded as to the rapidity of the warping in this region?

5. What must be concluded as to the rate of upwarping of the arch *MM'Q'Q*, 12 2, as compared to the rate of down-cutting by the river in the gorge *CD*? 6. Why may the river in the gorge *CD* be classed as an *antecedent* river? (*DP*, 258.2.) [7. The Sacramento river has its upper course on the broad basin plains of NE. California. Locate it on Plate 40. 8. Through what mountains does it then flow westward? What is the origin of these mountains? (See § 6, above.) 9. In these mountains the upper Sacramento river follows a deep, steep-sided, narrow gorge. To what class does this river belong? 10. The river Meuse flows N. from the open country of N. France, through a deep, narrow gorge in the arched Ardennes highlands to the lowlands of Belgium; locate the Ardennes on Plate 43. (See also *DP*, Fig. 160.) The highlands have a gently rolling surface; their broad crest extends E.–W. at an altitude of (about) 300–400 meters. The walls of the Meuse gorge and its side gorges show greatly disordered rocks. 11. Point out similar features in 12 2. (NOTE: There is nothing in N. France to correspond to the basin plain *BC*, 12 2.) 12. What do you think is the origin of the Ardennes? 13. To what class does the Meuse river probably belong? 14. Do you think that the uplift of the Sierra Nevada and the Ardennes was sudden or gradual? Why?]

10. 1. Draw in 12 2 a broken [red] line from *Q'* (W. of gorge *CD*) northward along the divide between the E.-sloping drainage area of the main river and the W.-sloping drainage area of several smaller rivers. 2. Where is the greatest change in this divide from the corresponding divide in 11 1? 3. Why may stream *K'*, 12 2, be described as having been *beheaded by warping?* stream *K*, 12 2, as *diverted by warping?* 4. Why has part of stream *K* been diverted by warping, while the main river *AE* has held its antecedent course in spite of the warping? 5. What sort of rivers (as to size) would most likely preserve their antecedent courses in a slowly warping region? 6. Draw broken and dotted [red] lines to mark some of the divides and subdivides of the small rivers *F*, *G*, *H*, in 12 2. 7. Are the divides and subdivides sharp and definite, or broadly

rounded and indefinite? [8. Draw similar [red] divides and subdivides in 37 1 and 37 2. Are the divides sharp or rounded?]

11. 1. What is the form of the waste (alluvial) deposits laid down in 12 2 by the rivers and streams at the base of the upwarped S. and W. slopes? (*DE*, 265.2; *DP*, 288.3; *G*, 42.8; *T*, 66.5.) 2. How many such forms can you count in 12 2? 3. Were these deposits made because of down-warping of the foreground (compare front borders of 11 1 and 12 2), or because of increase in the load of the streams? 4. Which of these fans may be described as independent? which as laterally confluent? [5. Draw a [red] line to represent a road running E.–W. about a mile N. of the front border of 12 2. Would it ascend or descend as it approaches the rivers *F*, *G*, *H*, *J*, *DE*? Explain. 6. Draw [blue] lines to represent each of these rivers in a new course on its fan. What difficulties would these river changes impose on road construction? 7. Draw a similar E.–W. road in 11 1. How does its relation to the streams differ from that of the road in 12 2?] [8. Why may the surface of a fan be described as *aggraded*, in contrast to that of a valley, which is said to be *degraded*? 9. What effect may the aggradation of a fan have in diverting rivers from their former courses (compare the lower courses of *F*, *G*, *H*, *DE*, in 11 1 and 12 2)? in changing the courses of small streams (examine the small streams E. and W. of river *DE*, 12 2, and compare them with the corresponding streams in 11 1)? 10. How may a small stream be turned across a former divide by the fan of a large river (examine the first stream W. of *D*, in 12 2 and compare it with 11 1)? 11. Which parts of the large river may be said to have a *braided* course (many islands of gravel and sand, dividing it into several channels)? a free meandering course in a plain (flowing in large curves, suitable to its large volume)? 12. Compare the fall of the river in its braided and its meandering course.] [13. The Hwang-Ho, a great river of China, flows out from a gorge in the mountains upon a great fan of gentle slope, where the river course has repeatedly changed. Locate the river on Plate 44. 14. Why is the river known as

"China's Sorrow"? What are the dimensions (height and radius) of its fan? (*DE*, 265.9–; *DP*, 289.2–; *T*, 67.6.)]

12. 1. Which parts of 12 2 present forms due to revived erosion following upwarping? forms due to aggradation following downwarping? forms little changed from 11 1, except for warping? 2. Where can parts of the former flood plain of the main river now be seen in 12 2? 3. Why is more of the flood plain preserved near the upper and the lower ends of gorge *CD* than about its middle? 4. Where (near head, middle course, or lower course) are the best preserved former flood plains of the smaller rivers and branch streams? Why? 5. In what part of these streams are the deepest new-cut valleys? 6. Why are the new-cut valleys less deep near the base of the sloping (upwarped) upland than in the mid-slope of the upland? deeper at mid-slope than farther upstream in the highland? [7. Why have the small tributaries of the main river in gorge *CD* cut new valleys (side gorges) of so much greater depth than the new-cut valleys of streams *F*, *G*, etc.? 8. Examine 16 13. To what part of 12 2 does it (in a general way) correspond? 9. Do the side streams in 16 13 make accordant or discordant (hanging) junctions with the main river? 10. Examine 16 14. To what part of 12 2 does it (in a general way) correspond? 11. Are the stream junctions here accordant or discordant (hanging)? 12. Explain why accordant junctions prevail in one case and discordant junctions in the other. 13. If a large tributary joined the main river in the gorge *CD*, 12 2, would the junction be accordant or hanging? Why?]

13. [1. Locate a city on the SW. lowland of 12 2; another on the basin plain; some villages in the NW. and in the SE. corners; give a name to each city and village. 2. Which settlements may be most easily connected by roads and railroads? Why? 3. Mark dotted [red] lines to indicate roads from the city on the basin plain to the other settlements. (Avoid new-cut valleys as far as possible; if they are crossed, the road should be laid obliquely on the valley sides, as in 16 14.) 4. Draw a [red] line to show a railroad connecting

the two cities, and passing over the arched highland. (The railroad must ascend the slope obliquely. Why? If it crosses new-cut valleys, imitate the route shown in 16 14.) 5. Where would this railroad cross the crest of the highland in 12 2 to best advantage? Why? 6. Draw another [red] line to show a railroad connecting the two cities by running through the river gorge. (Part of such a railroad is illustrated in 16 13.) 7. State some of the difficulties and some of the advantages of each railroad route. 8. Which parts of 12 2 might be cultivated for lowland crops? for highland crops (hardy grains)? 9. Which parts would probably remain forested? 10. Which parts are exposed to floods? 11. Is the main river navigable? 12. Which parts of it are obstructed by many shoals? by rapids and low falls? (See 16 13.) 13. The first Pacific railroad that was built (1866) to connect the cities of the eastern and central United States with those on the Pacific slope crosses the highlands of the Sierra Nevada in California; its irregular route over the crest of the highland is shown on the Colfax, California, map, *U. S. G. S.* 14. A railroad in Colorado follows the Arkansas river through the deep, narrow, steep-walled gorge that it has cut through the Front range of the Rocky mountains. (See Canyon City, Colorado, map, *U. S. G. S.*)]

14. 1. Note that Plate 13 is passed by for the present. Plate 14 is in two parts, — a SE. part (14 3) and a NW. part (14 4), representing a third and a fourth stage in the history of the district, of which the first and second stages are shown in 11 1 and 12 2. For the present disregard 14 4. 2. Compare the three-fork valleys of river *G* in 12 2 and 14 3, as to altitude of highland above headwaters; depth of new-cut valleys (valleys of revived erosion); sharpness of dividing ridges; amount of neighboring uncut upland or highland. [3. Shade lightly [red] some of the uncut uplands or highlands in 14 3.] 4. What has happened since 12 2 as to upwarping? as to erosion of valleys? as to destruction of highland surface? as to growth of alluvial fans? 5. Which differences between 12 2 and 14 3 have been produced by upwarping? by erosion? by deposition?

6. Follow line *WW'*, 14 3, and compare its course with the corresponding line in 12 2. 7. Draw a similar line *XX'* 14 3. 8. Why does so little uncut highland remain along this line? 9. Why are the ridges sharp-crested for most of their length? 10. Draw in 16 8 cross profiles for the branching valleys of river *G*, 14 3, a little S. of line *WW'*, and along line *XX'*. 11. Compare the low mountains near the E. border of 11 1 with the corresponding parts of 12 2 and 14 3, as to change of altitude; as to change of form. [12. Draw profiles in 16 16 to illustrate the original (×××) and the present (+++) form of these mountains.]

15. 1. The altitudes of points on the line *NN'*, 14 3, are indicated in 16 15 by dots in squares; of points on neighboring streams by double dots. 2. Draw in 16 15 the curve of the upwarped surface (as if it were uncut) along the line *NN'*, 14 3; draw the profile of the neighboring streams. 3. What is the average fall of the S.-flowing stream? Why may it be called a torrent? 4. Draw a light [red] line *MM'*, 14 3, along the divide between the N.-flowing and the S.-flowing streams. Which part of the divide is sharply defined? Which part is somewhat indefinite? Explain. 5. Compare this divide with the corresponding divide in 12 2 as to sharpness; as to number and steepness of its ascents and descents. 6. Draw broken and dotted [red] lines along some of the divides and subdivides of rivers *F*, *G*, and *H*, 14 3, and compare them with the corresponding divides in 11 1 and 12 2, as to sharpness. 7. Why are some of the ridges and mountains of 14 3 flat-topped? [8. Certain ranges of the Tian Shan mountains in central Asia (locate on Plate 44) have flat tops at altitudes of from 10,000 to 12,000 feet; they are dissected by deep valleys with steep walls, in which the disordered structure of the mass is clearly shown. A small part of such a range is shown in 14 3*a*. 9. What two processes have probably produced such mountains? 10. The dissected slope between the plateau of central France (NW.) and the lowlands near the Mediterranean (SE.) is called the Cévennes mountains; locate on Plate 43. Their structure is greatly disordered; their ridges and spurs decrease in height, and their

valleys decrease in depth to the SE.; most of the ridges have sharp and narrow crests, between steep-sided, sharp-V valleys, but some of the ridges are topped with even uplands, resembling the surface of the (as yet) undissected plateau farther NW. 11. What shares have warping and erosion had in producing the Cévennes?]

16. 1. Why may the name *pass* be given to some of the depressions in the mountain crest line *MM'*, 14 3? 2. How are the passes related to the neighboring valleys? 3. Is a pass found at the head of each small branch of the middle fork of river *G*? Explain. 4. Of several neighboring passes, which one would be most used? Why? [5. Draw a line (light on first trial, heavy afterwards) to show a road (or trail) from the southern lowland, 14 3, over the lowest pass in the crest line *MM'* to the inner basin *BC*. (Where the valley slopes are very steep, the road (or trail) may have to zigzag, as in 16 22.) 6. Draw a stronger line (light, at first) showing a railroad (see 16 29) from the fan of stream *H*, 14 3, obliquely ascending the slope W. of valley *H*, and then making its way to the inner basin *BC*. 7. Draw a dotted line to show the path by which cattle might be driven in summer from villages on fan *F* to highland pastures (*HH'*). 8. What peculiar feature is seen in the valley next NW. of the highland pastures? 9. How may it be related to a lake? 10. What disaster may happen when the lake overflows? (*DE*, 193.5; *DF*, 181.5; *G*, 107.2; *T*, 97.4.)] [11. Excellent roads of moderate grade have been built over many passes in the Alps, where there is much travel (*G*, Fig. 250; *T*, 185); but in most mountains the roads are steep and rough. Many ranges are crossed only by narrow trails. A railroad tunnel (Great Northern R. R.) passes under the crest of the Cascade mountains in Washington, between the upper parts of two opposite valleys. When the railroad was first built it ascended over the pass; the tunnel was made afterwards to lessen the ascent. (See Skykomish, Washington, map, *U. S. G. S.*) Another line (Northern Pacific R. R.) tunnels through two of the Rocky mountain ranges in western Montana, and through the Cascade mountains in Washington. (See Livingston, Montana, and

Snoqualmie, Washington, map, *U. S. G. S.*) Three long tunnels have been cut under passes in the Alps, for the passage of important railroads from Switzerland or SE. France to N. Italy (see *T*, Fig. 186); one of these tunnels (the Simplon tunnel) is 11.9 mi. long; seven years (1898–1905) were spent in cutting it, and it cost over $16,000,000.]

17. 1. Now examine 14 4 (the basin plain stands about 1000′ higher in 14 4 than in 14 3) and state the chief differences between its mountain range *QQ′* and the corresponding parts of 12 2, as to height; as to form; as to depth of valleys; as to ease of travel. 2. By what two processes have these differences been produced? 3. To what process do the mountains of 14 4 owe their altitude? their form? 4. Why is the term *sculpture* appropriate in connection with the form of such mountains? 5. What relation exists between amount of uplift and depth of sculpture? 6. Draw a [red] line along the mountain crest from *Q* to *Q′*, 14 4. 7. Why are none of the mountains flat-topped, like some of the summits in 14 3? 8. Are the passes in the range *QQ′*, 14 4, easier or more difficult to cross than the passes in the range *MM′*, 14 3? Explain. 9. Draw a [red] line in 14 4 from *O* at the W. base of the range, up the spur ridge, over the peak *O′*, and down the spur ridge to *O″* at the E. base. 10. Where, on this line, are parts of the original upwarped surface least eroded? Why? 11. Draw a curved [red] line from *O* to *O″* to represent the arched profile that the upwarped highland might have had if no erosion had taken place. (Let the crest of the arched profile be 1000′ or 2000′ higher than *O′*; see 16 20.) 12. How much upwarping has taken place here since 11 1? since 12 2? 13. Compare the mountain profile *O O′O″*, 14 4, with the (supposed) arched highland profile, as to height; as to form. 14. Make a statement regarding the mountains of 14 4, similar to this: "A statue is smaller than the block of marble from which it has been carved." 15. Compare the ridges *NN′*, 14 3, and *O O′O″*, 14 4. Make a statement regarding these ridges, similar to this: "After a knife blade is sharpened it is smaller than when it was dull."

18. [1. Why is much bare rock exposed on the peaks, ridges, and spurs of 14 4? 2. Why does much coarse angular rock waste lie on the slopes below the rock ledges? 3. Whence and how is the waste supplied to the slopes? 4. Why is it coarse and angular? 5. What becomes of it? 6. Draw in 16 20 [red] lines along the divides and subdivides, and [blue lines] along the streams. 7. How are the divides and subdivides arranged with respect to the stream and its branches? 8. Where are the streams steepest? 9. Are the stream junctions in 16 20 and in 14 4 accordant or hanging? Why? 10. The dotted parts of 16 20 represent waste-covered slopes. Why may the waste be described as "slowly streaming"? 11. Select in 14 4 a spur extending from a mountain peak to the mountain base; shade [red] the parts where bare ledges prevail (see 16 20); select another spur, and shade [blue] the waste-covered slopes. 12. Where is a *landslide* represented in 14 4? Why did the landslide take place? (*DE*, 193.6; *DP*, 181.5; *G*, 107.2; *T*, 97.4.) 13. What has happened since the slide took place? 14. How high are the walls of the *scar* that was left by the slide? About how long is the slide? How deep is the trench cut in the slide? How much higher has the lake (back of the slide) been than it is now?]

19. 1. The profile of the main river, 14 4, is shown by line $A^{iv}E^{iv}$, 16 9. In what parts of 14 4 has the river the strongest slope (lay a rule, or straight edge of paper, along the profile $A^{iv}B^{iv}$, 16 9)? the most rapid current? 2. How thick is the great fan of the main river at the front of 14 4? 3. Why does the river now flow on a higher profile than in 12 2? (Compare profiles $A''E''$ and $A^{iv}E^{iv}$, 16 9.) [4. If the river is at a greater altitude than before, why is the gorge of 14 4 deeper than that of 12 2? 5. What relation exists between the depth to which the gorge *CD*, 14 4, has been eroded, and the height to which the original surface has there been upwarped? Explain.] 6. Are the junctions of side streams and river, in the gorge, 14 4, accordant or hanging? [7. Compare with 12 2 and 16 13, and explain. 8. What does this suggest as to the rate of upwarping at the time of 14 4, as compared to rate at time of

12 2 ?] 9. Estimate the thickness of the gravel and sand deposits in the basin *BC* (see 16 9). 10. Compare the size of the fan S. of the mountains in 14 4 and 12 2. 11. In which figure may all the fans be described as "laterally confluent"? Why? 12. In which figure may the lowland surface bordering the mountains be described as a "piedmont deposit of mountain waste"? [13. Compare the opportunity for intercourse and trade between the people of the W. plain and the inner basin plain in 12 2 and 14 4. 14. Draw a dotted [red] line in 14 4 to show (as much as can be seen of) a trail over the mountains, connecting the two plains. (Avoid crossing the larger streams, if you can; see the broken line, 16 20.) 15. Describe a trip on foot over the range.]

20. [1. 37 3 is a small part of the Rocky mountains; locate it on Plate 40. In what state is it? What is the scale (miles to an inch)? the contour interval? 2. Mark H on the highest summit. What is its altitude? What are the altitudes of several other summits? of Conundrum creek? 3. How high are the summits above the creek? 4. Are the peaks and ridges flat-topped or sharp? 5. What is the usual difference between peak and pass altitudes in the mountain crests? 6. Draw a [red] line along the crest of each mountain ridge in this figure; broken [red] lines from the crest down several spurs. 7. Mark S on a short spur that ends between the forks of a branch of Conundrum creek; L on a long spur that extends without dividing from the mountain crest to Conundrum creek; D on the separate lower ends (or spurlets) of a spur that is divided by short branches of Conundrum creek. 8. Print 5 on a spur that divides into five spurlets; print 6 on a slope that is divided into six short spurs between the forks of one branch of Conundrum creek. 9. Draw a dotted [red] line to show a trail from some point on Conundrum creek to the W. border of the map. 10. How did you determine where the trail should cross the W. range? 11. Is the sculpture of these ranges farther advanced than the sculpture of the mountains in 37 1 and 37 2? How can you tell? 12. Of these three mountains, which would you describe as maturely

dissected? which as in an early (young) stage of its cycle of erosion? 13. 37 4 is part of the San Antonio mountains; locate on Plate 40. In what part of what state is it? What is the scale? the contour interval? 14. What is the greatest altitude shown? 15. Is the dissection immature or mature? 16. Compare in 37 3 and 37 4 the pattern of the contours; the size of the spurlets. In which of these two maps might the dissection of the mountains be described as of finer texture? 17. Describe the form of the S. part of 37 4. Explain its origin. What name is given to such forms? Where does a similar form occur in 14 4? 18. The basin plain or "vale" of Kashmir lies between the outer and the inner ranges of the lofty Himalaya mountains in NW. India; locate it on Plate 44. It is 100 mi. long by 50 mi. wide, and 5000′ above sea level; the passes in the inclosing mountain range have an altitude of over 10,000′. The vale is occupied by a people who differ in various ways from the people of the outer piedmont plains. 19. The river Jhelam flows from the inner basin plain through a deep, narrow, steep-walled gorge in the inclosing mountains to the outer plains; the native people have therefore crossed the inclosing range for centuries only by a high pass; in recent years British engineers have built a road part way through the gorge. (*DP*, 284.6–.) 20. Point out some similar features in 14 4.]

21. Now turn to Plate 13. NOTE: 13 5 and 13 6 represent later stages of the district already studied in 11 1 to 14 4; for the present do not consider 13 6. 1. Compare the W. range in 14 4 and 13 5 as to height; as to sharpness of peaks, ridge crests, and spurs; as to slope of valley sides; as to steepness of stream profiles. Explain the differences. 2. Which one of these two ranges has the greater amount of bare ledges? of waste-covered surface? (See 16 19 and 16 20, in which the waste-covered surface is dotted.) 3. By what process can you account for the differences? 4. When did the greater amount of upwarping take place, between 12 2 and 14 4 or between 14 4 and 13 5? 5. Why may the waste-covered slopes in 13 5 be described as "graded"? the bare rock ledges as "not yet graded"?

the rounded summits, crests, and spurs as "subdued"? (*DE*, 204.8–; *DP*, 187.1–.) 6. Draw in the upper part of 16 17 a cross profile of the spurs and valleys on the line *XX'*, 13 5. 7. Compare it with profile *XX'*, 16 8, and explain the differences. 8. Compare the main river in 14 4 and 13 5 as to altitude at *A* and *E*; as to fall and velocity from *A* to *E*; as to amount and texture of waste received from tributaries. 9. In a river of given volume what relation exists between its load (amount and texture of waste) and the slope to which it may wear down its profile? (*DE*, 254.9; *DP*, 243.2.) 10. Why have the rivers of 13 5 begun to degrade the alluvial fans and plains that they previously aggraded? NOTE: The remaining parts of the fans and plains (dotted in 12 2, 14 3, and 14 4) are unshaded in 13 5. 11. What features in the valley *CD*, 13 5, indicate whether the river is or is not still deepening its valley? Explain. 12. Why was not the widening of the valley bottom begun at an earlier stage (as in 12 2 or 14 4)? 13. What can you infer from this as to whether the warping and uplift of the region is still going on or not? [14. The Black mountains of North Carolina possess many of the features here described. Their summits, ridges, and spurs are rounded; their slopes are graded, with few cliffs or ledges; their valleys are usually open; their streams commonly have narrow flood plains.]

22. [1. What features in 16 10 indicate that the river has been cutting laterally (sideways) as well as downwards during the erosion of its gorge? 2. Draw a full [or red] line along the *outer* bank of each river curve (or meander) in 16 10, 11, 12; draw a dotted [or blue] line along the *inner* bank of each curve. 3. Are the dotted [or blue] lines all on the same side of the river? How are they arranged? 4. Let the steeper parts of the gorge wall be called the *undercut slopes*, or *undercut amphitheaters;* shade them lightly [red]. 5. Call the less steep parts the *slip-off slopes*, or *slip-off spurs;* dot them [blue]. 6. Explain why the preceding terms are appropriate. 7. What relation exists in 16 10 between the outer bank of a river curve and the undercut slopes? between the inner

bank and the slip-off slopes? 8. In which one of 16 10, 11, 12, is the river bordered by narrow *flood-plain scrolls?* by wider *flood-plain scrolls?* 9. Where are the flood-plain scrolls situated with respect to the inner and outer banks of the river curves (or meanders)? with respect to the undercut slopes? to the slip-off slopes? 10. In 16 10, 11, 12, draw a nearly straight line touching the river curves on the right; another on the left. 11. The space included between each pair of lines may be called the *meander belt.* How does its width change? 12. During the erosion of the gorge, 16 10, which was greater, downward river erosion or lateral river erosion? 13. During the development of the flood-plain scrolls, 16 11, 16 12, which was greater, downward or lateral river erosion? 14. If the downward erosion (or deepening) of the gorge resulted from the revival of river erosion by the upwarping of its district, does the upwarping still continue or has it ceased, now that flood plains are developing?]

23. [1. Shade [light red] three undercut slopes on the W. side of the main river gorge *CD*, 13 5; three on the E. side. 2. Mark with [light blue] dots three slip-off slopes, or spurs, on each side of the gorge. 3. Shade [light red] three flood-plain scrolls on each side of the river in the gorge. 4. Are the flood-plain scrolls on the up-valley side or the down-valley side of the spurs? 5. Why may the spurs that adjoin the flood-plain scrolls be described as "trimmed on the up-valley side"? (See also 16 21, looking across a valley.) 6. Why may the spurs on the farther side of the valley, 16 18, be described as "nearly consumed"? 7. With which stage of flood-plain development, as shown in 16 11 (narrow flood-plain scrolls), 16 12 or 21 (broad flood-plain scrolls), and 16 18 (broad flood-plain *lobes*), do the flood plains in the gorge of 13 5 best correspond? 8. With which stage of spur erosion, as shown in 16 11 (little-trimmed spurs), 16 12 or 21 (well-trimmed spurs), and 16 18 (nearly consumed spurs), do the spurs in the gorge of 13 5 best correspond?] [9. Draw in 13 5 a broken [red] line to show a road, and a full [red] line to show a railroad, crossing the W. mountain range. (See

16 19 ; the road is here a single line, the railroad a double line.) 10. Draw a [red] line to show a railroad following one side of the valley *CD*, 13 5. 11. What part of this railroad would have to be built on steep slopes ? 12. A railroad of this kind follows the deep meandering valley of the N. branch of the Susquehanna river in Pennsylvania ; another follows the similar valley of the Mosel river in W. Germany. (*DP*, 254.5.)]

24. 1. Examine 13 6 and compare it with 13 5, as to altitude ; as to relief ; as to steepness of hillside (or valley-side) slopes ; as to breadth of flood plains along small streams. 2. Explain the differences. 3. Which has been the more important, warping or erosion, in causing the change from 11 1 to 12 2 ? from 13 5 to 13 6 ? [4. In 14 3 and 14 4 which is the more rapid, the deepening of the valleys or the wearing down of the peaks ? 5. Answer the same question for 13 5 and 13 6. 6. Explain the difference between the answers to these two questions. 7. Is the wearing down of the summits faster in 14 4 or in 13 6 ? 8. What conclusion is suggested by answers to questions 5 and 7, as to the rate of valley deepening in 13 6 ? 9. Would you expect bare rock, thin soil, or deep soil on the sharp divides of 14 4 ? on the rounded divides of 13 5 ? on the low divides of 13 6 ?] 10. Draw in the middle of 16 17 a profile on *XX'*, 13 6 ; draw below this another profile representing a later stage of erosion than 13 6 ; below this again a still later stage. 11. In what way do these three profiles differ ? 12. Would the change from one to the other be quickly or slowly produced ? Why ? 13. When the district here studied reaches a later stage of erosion than is shown in 13 6, which one of the figures 11 1 to 13 5 will it most resemble ? 14. What, then, is the probable explanation of the forms shown in 11 1 ? 15. Such a district may be called a *peneplain* (that is, almost plain). 16. What relation has a peneplain to baselevel ? to the underlying rock structures (such as are shown in the front sections of 16 13 and 16 20) ? 17. Suppose that part of a district like the one here considered consisted of much more resistant rocks than the rest. What features would you expect to survive in the

area of the very resistant rocks, when the less resistant parts were worn down to a peneplain? 18. In which figure of this series are such features represented? NOTE: Such residual hills or low mountains may be classed as *monadnocks*. (*DE*, 207.6; *DP*, 190.1; *G*, 87.9; *T*, 298.6.) 19. If a seventh figure were drawn, representing a later stage than 13 6, where would you expect to see a group of monadnocks? [20. How do the monadnocks in 12 2 differ from those in 11 1? 21. A large area in W. Siberia around Omsk is a peneplain of small relief, with occasional monadnocks. Between what mountains does this peneplain lie? by what river is it drained? (See Plate 44.)]

25. [1. What two unlike processes are concerned in a "cycle of erosion"? NOTE: Let the successive stages of a cycle of erosion be called "early youth," "youth," "early maturity," "full maturity," "late maturity," "early old age," "late old age." 2. Which of these terms may be used in describing the figures, 12 2 to 13 6? 3. Does 11 1 belong in the same cycle of erosion with the following figures? 4. What sort of movement interrupted the cycle of the first figure and introduced the cycle of the later figures? 5. In what stage was 11 1 when its cycle of erosion was interrupted? 6. In the early youth of a new cycle which parts of the surface preserve forms little changed from the old age (peneplain) of a previous cycle? 7. In the stage of full maturity (strongest relief and greatest variety of form), how would the divides differ from their form in youth? from their form in old age? 8. How would the load of the rivers differ in maturity and in old age? 9. How would the streams of youth differ from those of old age as to slope? as to the occurrence of falls and rapids? 10. Which stage, youth, maturity, or old age, occupies the longest time in a completed cycle of erosion? 11. Is it necessary that a cycle of erosion should continue without interruption (by uplift, warping, or depression) until late old age? 12. Suppose that interruption by uplift occurred at the stage of 13 5; describe the forms of the district in a young stage of the new cycle of erosion thus introduced.

13. What features would you expect in a region that had been worn down to a peneplain (with a few monadnocks) in a long, undisturbed cycle of erosion, and that had then reached early maturity in a new cycle introduced by a broad uplift of 600′ or 800′? 14. The Appalachian Piedmont belt of Virginia, the Carolinas, and Georgia (locate it; see *DE*, Fig. 100; *DP*, Fig. 117) is such a region; many other examples of peneplains, upwarped and more or less dissected, might be mentioned. 15. Locate 37 5 on Plate 40. 16. What is the general altitude of the uplands? 17. How much higher is Stone mountain than the uplands? 18. How deep are the valleys below the uplands? 19. The uplands are part of the uplifted Appalachian Piedmont peneplain. How many cycles of erosion are here represented? 20. What stage had the first cycle reached when it was interrupted by regional uplift? How can you tell? 21. What stage has now been reached in the new cycle of erosion? How can you tell? 22. What term already used would apply appropriately to Stone mountain? 23. Make a list of the features which characterize the youthful stage in a cycle of erosion; the mature stage; the old stage.]

26. Define: § 1, interfluve; § 2, well-defined divides, ill-defined divides; § 4, an arched or upwarped district, [river beheaded by warping,] torrent; § 5, revived or rejuvenated stream, sharp V-shaped valley; § 8, basin plain, bent-down or down-warped basin; § 9, antecedent river; § 10, river diverted by warping, beheaded by warping; § 11, alluvial fans, laterally confluent (alluvial) fans, aggrade, aggradation, degrade, degradation, braided river course, meandering river course; § 16, pass; § 17, mountain sculpture; [§ 18, landslide;] § 21, subdued mountains; [§ 22, undercut slopes, slip-off slopes, flood-plain scrolls, meander belt; § 23, trimmed spurs, flood-plain lobes;] § 24, peneplain, residual mountain, monadnock; [§ 25, interruption of a cycle of erosion].

EXERCISE VI. VOLCANOES AND LAVA FLOWS

OBJECT. **To illustrate the various forms of volcanoes and lava flows, and the effects that they produce on land sculpture by rivers.**

Preliminary. 17 1 to 19 8 of this exercise represent the same piece of country (shown as a block, cut out from its surroundings), at different stages in the history of a group of volcanoes and their associated features. The NW. and SE. corners of the figures are cut off to save space. The complete block would measure about 4 mi. N.–S. by 5 mi. E.–W. Scales of miles are marked on the S. and W. baselines; a scale of altitudes (feet) is given on the SW. corner. The numbers on the upland indicate altitudes in feet above sea level. Plates 17, 18, 20, 19, and 15 are used in this exercise [also 38 3]. Note that Plate 20 is to be used before Plate 19.

1. 1. What is the general altitude of the upland in 17 1? its general measure of relief (general height of uplands over valley floors)? (The uplands are not level, but slope gently toward the valley sides, as shown on the S. border of the block.) 2. What is the average fall of river *UV* in feet per mile? (Use scale on W. baseline for river length.) 3. What is the altitude of the pass *X* between the valleys of river *UV* and of river *YY'*? 4. Draw a dotted [red] line along the divide between the *V* and the *Y* river systems. 5. Draw a [pencil] line on a direct path from *C* to *C'*; from *D* to *D'*. (Follow the heavy hachure lines downhill and uphill.) 6. Draw to scale in 15 9 a cross profile of *UV* valley at *CC'* and *DD'*.

2. 1. What are the three chief events that have taken place in the change from 17 1 to 17 2? 2. What is the height of the volcano summit above sea level in 17 2? above the neighboring upland? the diameter of its base (use scale on S. baseline)? of its *crater?* [3. What is (roughly) the volume of the volcano? NOTE: The

volume of a cone = area of base × ⅓ height; the area of the (circular) base = 3¼ × square of radius.] 4. Why did the *lava flow* turn S. in *UV* valley? 5. Is the lava flow higher along its middle or along its sides? 6. What effect has the flow had upon the position of the junction of river *ZZ* with river *UV*? 7. What is the length of the flow (use scale on W. baseline)? average breadth of flow (use scale on S. baseline)? thickness of flow at mid-length? (In answering the last question compare altitude of flow surface in 17 2 with altitude of corresponding points in valley floor, 17 1.) [8. What is (roughly) the volume of the flow? NOTE: Multiply length × average breadth × ½ average thickness along valley line. 9. Which has the greater volume, the cone or the flow?]

3. 1. Why have several *lakes* been formed in 17 2? 2. Determine the length, breadth, and greatest depth of lake *A*. 3. Why is the outlet of lake *A* along the W. side (instead of the E. side) of the lava flow? 4. If the altitude of lake *C* is 1900′, what is the average fall of river *UV* in feet per mile from the lake to the end of the flow? 5. Why is this average fall greater than that of river *UV* in 17 1? 6. Why has a narrow gorge been cut along the W. side of the lava flow of 17 2 between lakes *A* and *C*? Why has a gorge been cut on each side of this lava flow near its end? 7. Why is there no gorge along the E. side of the lava flow near *F*′? 8. Estimate the breadth and depth of each gorge. 9. Draw a [pencil] line on a direct path from *E* to *E*′, crossing lake *A* and going over the volcano; from *F* to *F*′; from *G* to *G*′. [10. In 15 10 draw cross sections for the three profiles, showing in *EE*′ the bottom of the lake, the base of the volcano, and the passage or *pipe* up through which the lava *neck* rose from its deep source; in *FF*′ the base of the lava flow, and the old and new course of river *UV*; in *GG*′ the base of the flow, and the larger and smaller gorges.]

4. [1. A small volcano called Monte Nuovo (New Mountain) was formed by sudden eruption on the N. border of the gulf of Naples in 1538. (*DE*, 218.6; *DP*, 202.6; *T*, Fig. 207.) 2. To what does Monte Nuovo correspond in 17 2? In what part of Italy is it?

(See Plate 43.) 3. A smooth cinder cone in California is believed to have been erupted about 200 years ago; a younger lava flow near the cone produced Snag lake, so called because the dead trunks of trees that grew before the eruption are still to be seen there. (*DE*, 219.8; *DP*, 203.8; also J. S. Diller, *Bull. 79, U.S.G.S.*; good description and many excellent plates.) 4. To what do these features correspond in 172? In what part of California is Snag lake? (See Plate 40.) How far and in what direction from Mt. Shasta? 5. In 1759 the volcano Jorullo (pron. *Ho-rul-yo*), in Mexico, was rapidly built of lava and cinders, its crater rim rising about 700′ over the lava flows around its base; fine *cinders* or *ashes* and *dust* were showered on the cone, the flows, and the surrounding country. 6. Locate Jorullo on Plate 41. How far and in what direction is Jorullo from Popocatapetl? The cone, lava, and ashes of Jorullo were barren for many years, but they are now more or less covered with vegetation. (*DE*, 219.1; *DP*, 203.1.) 7. Lava flows, cascading down high cliffs in Arizona, are shown in Atlas, sheet V, of *U.S.G.S., Monogr. II* (copied (in part) in *DE*, Fig. 113; *DP*, Fig. 129). 8. Where was a *lava cascade* formed in change of 171 to 172?]

5. 1. 1511 is a map, partly in 100′ contours, partly in hachures, of a volcano, its lava flows and a portion of the surrounding country; the contours are dotted on the non-volcanic surface; the scale is 1:62,500. 2. What is the diameter of the cone at its base? the height of the cone above the hilly upland? [the angle of slope of its sides?] 3. Draw [red] lines along the middle of each flow, and shade lightly [red] the surface of the cone and flows. 4. Why does the E. flow widen where its mid-line is 1650′? 5. About how much higher is the mid-line of the E. flow than its N. border? than its S. border? 6. What is the average fall along the mid-line? NOTE: The lava of flows as steep as those here shown must have been viscous when erupted; the more fluid the lava, the less the slope of the flows when they solidify. 7. Draw dotted [blue] lines to represent the (probable) stream courses before the volcano was formed. 8. Shade [light blue] the four small lakes. Why were they

formed? 9. Mark ○ at the lake outlets. 10. What is the altitude of the outlets? 11. Draw full [blue] lines to represent the present streams, and darken the lines where gorges will be cut. 12. Why is a single former stream now represented by two streams for part of its length? [13. Estimate the thickness of the E. flow where its mid-line is 1400′, 1700′, 1800′, and 2000′. 14. In what part of the flow is its thickness greatest, — close to base of cone, midway along the flow, or near end? Why?] [15. Draw in 15 12, scale, 1 : 62,500, with 100′ contours, a volcano 2100′ altitude at *V*, with lava flows extending E. and SW. (The numbers by crosses (×) indicate altitudes at middle and side of the flows.) 16. Indicate, as above, the drainage before and after eruption. 17. Mark ○ at the outlets of the several lakes. (Some of the outlets are close along the lava flows; one is across a divide between former streams, like *X*, 17 2.) 18. Shade the lakes [light blue], and draw dark [blue] lines where gorges will be cut. 19. What is the angle of slope of cone? length, breadth, greatest thickness, and fall per mile of mid-line of each flow? length, breadth, and greatest depth of each lake? 20. Draw lines to show the former [dotted red] and the present [full red] divide between the NE. and the SW. river systems.]

6. 1. What are three chief differences between 17 2 and 18 3 directly due to volcanic eruption? 2. What has happened in 18 3 to lake *B* of 17 2? Explain. 3. What is the altitude of the W. border of the large new lava flow near *H*, 18 3? 4. How much higher is the surface of lake *A* in 18 3 than in 17 2? Why is it higher? 5. To what river does lake *A* overflow in 18 3? 6. Explain this change from 17 2. 7. How much higher has lake *A* been than it is now? (See *X*, 17 2.) 8. What new feature has been produced along the outlet of lake *A* in 18 3? Explain. 9. Draw a [blue] line along the outlet stream of the two small lakes W. of the lava flow in 18 3. 10. Why does the outlet stream follow this course? 11. Draw a [red] line in 18 3 along the divide between river systems *VZ* and *Y′*. 12. Why does this line differ from the corresponding line in 17 1? 13. Compare the volume of river *V* at

the S. border of 17 1, 17 2, 18 3; of river Y' at E. border of each figure. Explain the changes. 14. In 18 3 why is the gorge of river Z deeper than the gorge of river Y'? 15. Draw a [pencil] profile line in 18 3 from H directly across the newer lava flow, over both volcano summits, to H'; from J across both lava flows to J'; from K to K'. [16. In 15 10 draw cross sections corresponding to these profiles, and show in section HH' the bottom of the newer lava flow, the base of both volcanoes, and the pipes by which the lava has risen; in sections JJ' and KK', the surface and bottom of each flow, the newer one burying the gorge previously eroded along the W. border of the older one (see 17 2).] [17. What large lake in Central America is due to a volcanic barrier? (*DE*, 231.9–.) Locate this lake on Plate 41. 18. What river has thus been made to flow across the former "continental divide" between the Atlantic and Pacific oceans? Explain.]

7. 1. What are the chief changes from 18 3 to 18 4 as to volcanoes? as to lava flows? as to lakes? as to lake outlets? (Lake Y and river Y' are separated by a divide, 2900′, on the NE. border of the NE. lava flow.) 2. What is the height of the great volcano above the uplands around its base? the diameter of its base? [its volume, compared to that of the volcano in 17 2?] 3. What change has taken place in the form of the larger volcano of 18 3? 4. Explain why it may now be called a "dissected volcano." 5. What has become of the smaller volcano of 18 3? 6. Why are the ravines of so moderate a depth on the slopes of the great volcano, 18 4? (Many ravines, eroded to a considerable depth while the volcano was smaller, may have been filled with lava and ashes by later eruptions.) [7. Fujiyama, a great volcano in Japan (between Tokyo and Kyoto; locate on Plate 44) is a nearly symmetrical cone rising about 14,000′ close to the seacoast; its slopes are but moderately dissected by radiating ravines. In what part of what island is this volcano? 8. Mt. Shasta is a large volcano of similar height in California. (*DE*, 229.9–; *DP*, 214.1; *G*, 211.9; *T*, 121.5; also J. S. Diller, *Nat. Geogr. Monogr. No. 8.*) 9. In what

part of California is Mt. Shasta? (See Plate 40.) What is its altitude? Compare its dissection with that of the larger and smaller volcanoes of 18 4.]

8. 1. How many lava flows are shown in 18 4 around the base of the great volcano? 2. What is the relative age of the SW., S., and SE. flows? Explain. 3. How many different lava flows are shown on 17 2, 18 3, and 18 4? (Include the two small flows in the center of 18 3, and the several larger flows shown in section on the S. face of 18 4.) 4. What is the total thickness of the four flows shown in section on the S. face of 18 4? 5. Why is the under surface of these flows uneven? [6. How can you estimate (roughly) the relative duration of the time intervals between the outpouring of these four flows? 7. Were they about equal or very unequal?] NOTE: The flows that issue from the flanks of a volcano (as here or SW., S., and SE.) are probably supplied through great underground fissures, splitting the earth's crust outward from the central pipe of the cone. The lava that solidifies underground in such fissures forms *dikes*. [8. Numerous barren lava flows are found around the volcanoes of Mexico. The surface of the lava is often so rough as to be nearly impassable. Why? (*DE*, 227.7; *DP*, 209.8; *G*, 198.7.) 9. Such flows are called *malpais* (bad country). A large malpais near (S. of) the City of Mexico was formerly the resort of robbers and outlaws, who, knowing their way over it, found refuge from pursuit in its caverns. In what part of Mexico is this malpais? (See Plate 41.)]

9. 1. About how far W. of its course in 17 1 is river *V* in 18 4? 2. Was the displacement made all at once? In how many partial displacements? (Examine 17 2, 18 3, and 18 4.) 3. Draw a [red] line in 18 4 along the divide (as far as you can see it) between river *Y'* and the other rivers. 4. Compare in 17 2, 18 3, and 18 4 the volume of river *Y'*; of river *V*; explain the changes. 5. Where do rivers *V* and *Z* now (probably) unite? 6. How much wider than now was the large SW. lava flow when it was poured out? Explain. [7. Draw in 15 13 a cross section of valley *V*, 18 4, at *LL'*;

of valley *Z* at *MM'*. Why are these two valleys not of the same shape? 8. Indicate (dotted lines) in sections *LL'* and *MM'* the original upland surface and the original border of the lava flows. 9. What relation exists between the original border of the lava flows and the present river courses? 10. Draw in 15 14 a cross section from *N* to *N'*, 18 4, showing the original upland and valley profile, and the pipes, cones, and flows that are crossed by the section. 11. Which lava flows of 18 3 and 18 4 are shown in this *NN'* section? How many volcanic pipes are shown?]

10. Turn to Plate 20. (Plate 19 is passed by for the present.) 1. Does 20 5 show any signs of volcanic action later than the latest lava flow of 18 4? 2. What changes has the great volcano suffered? Why may it be called a dissected volcano? 3. Why do its valleys radiate from its center? How many such valleys do you think there are in the larger volcano? in the smaller volcano? 4. To what class do these valleys belong? [5. How many feet has the height of each volcano been decreased? (Lay a piece of tracing paper, about 6 × 7 inches, on 18 3; mark the SE. and SW. corners of the block base and the summit of the W. volcano; lay the tracing paper in the same position on 18 4, and mark the summit of the great (E.) volcano. Lay the paper in the same way on 20 5, and mark the summit of each volcano; measure decrease of height by vertical scale on SW. block corner.) 6. How many feet has the upland, not covered by lava, as at the SE. corner of the block, 20 5, been worn down? (Use the same tracing paper and trace the front profile of upland near SE. corner from 17 1 and 2, 18 3 and 4, and 20 5.) 7. Why has the upland not been worn down so much as the volcanoes? 8. How many feet has river *V* cut down its present valley near the SW. corner of the district? (Trace front profiles of valley, from 18 3 and 4 and 20 5.) 9. How much has the general surface of the large lava flows been worn down since their eruption? (Compare front border sections of SW. flow in 18 4 and 20 5.) 10. Compare the amount of erosion of volcano summits, general upland surface, general lava-flow surface, and river valley *V*.]

11. 1. About how many feet has the (uppermost) SW. lava flow in 20 5 been narrowed? 2. Has it lost more on the W. or on the E. side? Why? 3. Why has erosion been greater (more rapid) on the W. side than on the general surface of the flow? 4. Name some other parts of 20 5 where similar changes have taken place. 5. If you ascended from river *V*, first to the upland on the W., then to the lava flow on the E., what difference would you find in the rock waste on the valley sides? 6. Where would corresponding kinds of rock waste be found in valley *Z*? 7. How can the term *talus* be used here? 8. Why do the streams of two southwestern valleys of the great volcano unite before reaching river *Z*? 9. Why is the gorge of the united stream narrower than the valley of *Z*? 10. In what other part of 20 5 is a similar gorge shown? Why? 11. About how many feet has the valley on the N. side of the smaller volcano been deepened? 12. Why do the streams on the N. and S. sides of this volcano unite before reaching river *UV*? (Examine 18 4.) 13. Why are there no lakes in 20 5? 14. Draw a line in 20 5 across valley *UV* from *Q* to *Q'*; across valley *Z* from *R* to *R'*. [15. Draw sections in 15 13 corresponding to the profiles *QQ'*, *RR'*, 20 5.] 16. Name, describe, explain, and indicate by appropriate letters the features shown in 15 16 (scale, about 1:62,500), which resemble certain features of 20 5. [17. Complete the contours in the NE. part of 15 16.]

12. [1. A large volcano on Tahiti, one of the Society islands in the S. Pacific ocean, has been so greatly dissected that it is now hardly more than a skeleton of radiating ridges. (See Dana, *Revised Textbook of Geology*, p. 130; or *Manual of Geology*, fourth edition, p. 180.) 2. The Cantal is a deeply dissected volcano in France; it is estimated to have lost about a mile of its original height. A road and a railroad, following up one valley, tunneling through a ridge and then following down another valley, pass almost through the center of the volcano. 3. In what part of France is the Cantal? (See Plate 43.) 4. Enormous lava flows form extensive plains in Idaho, Oregon, and Washington. 5. What parts of each state does the lava cover?

(*DE*, Fig. 114; *DP*, Fig. 130.) 6. The level borders of the most recent flows contour around the inclosing mountains, as the ocean contours around the continents; ridges stand forth in the lava plain like promontories; the lava plain enters valleys between the promontories, forming "bays"; outlying mountains rise like islands over the plain; deep canyons, cut by Snake river and its branches, disclose lower mountains buried under the heavy lava sheets. (*DE*, 228.9; *DP*, 211.4; *G*, 213.8; *T*, 125.9; see also I. C. Russell, *Water-supply paper, No. 4, U. S. G. S.*, especially pp. 36, 38, 34; also, by same author, *Bulls. 199, 217, 252, U. S. G. S.;* many excellent plates; also, by same author, *Volcanoes of North America.*) 7. Smaller lava flows form a plateau (the Mesa de Maya) in Colorado. In what part of the state are these flows? (See Plate 40.) In what stage of dissection is this lava plateau? (See 36 2 and 3.)]

13. 1. The variable succession of events in a volcanic district may be illustrated as follows: Instead of passing from 18 4 to 20 5, let 15 17 follow 18 4. 2. What appears to have happened to the great volcano of 18 4 in 15 17? 3. The large cavity in the cone is called a *caldera;* compare the caldera of 15 17 with the crater of the great volcano in 18 4, as to diameter; as to depth. [4. Can the caldera have been formed, like a valley, by ordinary stream erosion? Explain. 5. Do the lava flows appear to be covered with the products of an explosive eruption, or do they remain as they were in 18 4? 6. How can such a caldera be best explained? (*DE*, 221.2; *DP*, 218.8; *G*, 217.6; *T*, 122.1.) 7. Compare 18 4, 15 17, and 20 5 as to opportunity of examining the internal structure of a volcano.] 8. If eruptions begin again, a new cone and new flows may be formed, burying earlier forms. Describe 15 18 as to the forms there shown; as to the succession of events there indicated. 9. If an outflow of lava occurs after a cone of "ashes" has been built, a great cavity, or *breach,* may be opened in the side of the cone; if the cone is enlarged by eruptions of ashes after the flows have ceased, the form of the cone is more regular. 10. Compare the cones of 17 2, 18 3 and 4, and 15 18 in these respects. 11. Which of the lava flows in these figures

appears roughest? [12. An extremely ragged lava flow breaches the N. side of the cone of Jorullo. 13. "Crater lake" occupies a great caldera in a broken-down volcano in Oregon, mapped in 38 2. (*DE*, 222; *DP*, 215.9–; *G*, 217.6; *T*, 121.8. See J. S. Diller, *Nat. Geogr. Mag.*, VIII (1897), 33–48.) 14. In what part of Oregon is Crater lake? (See Plate 40.) How far N. of Mt. Shasta? 15. What are the dimensions of this caldera? How is its origin best explained? 16. What reasons can you give for describing Vesuvius (locate on Plate 43) as "a large cone built over the western rim of a great caldera"? (*DE*, 221.8; *DP*, 213.3; *T*, 117.3.) What is the name of the E. rim of this caldera? 17. If a breached caldera stood in the ocean, describe the shape of the island that it would form? 18. Name and locate such an island. (*DE*, 221.5; *DP*, 213.2; in S. Shetland islands, Plate 42.) What is its diameter?]

14. 1. Why have some dissected volcanoes a central peak or neck, as in 20 6? 2. Examine the side slopes of the spurs of this great volcano, and note a difference of shading above and below a certain level. Draw a [pencil] line along this level on several spur sides; the altitude of this line is about 3100′. 3. What is thus indicated as to the depth now reached in the dissection of the volcano? (Examine 17 1 and 18 3 as to altitude of the central uplands.) [4. How much loss of altitude has taken place on the central summit of the great volcano in the change from 20 5 to 20 6 (use the same tracing paper as in § 10)? on the even surface of the SE. upland? on the general surface of the SW. lava flow (away from streams)? on the valley floor of river *Z*? of river *V*? 5. Why has valley *V* not been as much deepened by its large river as the volcano summit has been lowered by weather and small streams?] [6. Why does a row of sharp knobs occur on the SW. spur of the great volcano, 20 6? (See note following question 7, § 8.) Where do similar knobs occur? Why? 7. Draw in 15 15 a section crossing the SW., SSW., and S. spurs of the great dissected volcano of 20 6, and show the features referred to in question 6. 8. Why has the middle spur a different cross profile from the other two?]

15. 1. Why are the borders of the lava flows in 20 6 more irregular or "ragged" than 20 5? 2. Has the change of form occurred chiefly on their upper surface or around their borders? Why? 3. Why are the borders marked by a vertical cliff above a steep, talus-covered slope? 4. How can the term *retreat* be used in connection with the changes of the bordering cliffs? 5. How can the term *sapping* or *undermining* be used in connection with the retreat of the cliffs? 6. Which is the more resistant, the *country rock* of the district or the lava of the flows? 7. Why do the lava flows now form *table mountains?* 8. Explain the relation of the several table mountains of 20 6 to the valleys of 17 2 and to the lava flows of 18 4. 9. Where are the river gravels of the original valley *UV*, 17 1, now preserved? 10. Suppose that the gravels contained grains of gold, how could the gravels be best mined? [11. What is the origin of the small knobs E. of valley *V* near the SW. corner of 20 6? 12. In 15 13 redraw sections *QQ'* and *RR'* so as to make them correspond with 20 6 instead of with 20 5. (The proper depth of valleys *V* and *Z*, 20 6, is indicated in 15 13 by dots below sections *QQ'* and *RR'*.) Draw in 15 16 the outline of the middle table mountain when its length, NE.–SW., is reduced by half; of the E. table mountain when it is reduced to a butte.]

16. [1. Many volcanic knobs or necks occur near Mt. Taylor, a deeply dissected volcano in New Mexico. (See article by Dutton, *6th Ann. Rep., U.S.G.S.*, p. 164.) Locate Mt. Taylor on Plate 40. 2. Is volcanic action in that district recent or ancient? Why? 3. A fine table mountain, called Raton *mesa* (pron. *may-sa;* Spanish for "table"), surmounts the plains adjoining the Rocky mountains, W. of Mesa de Maya in Colorado; part of it is mapped in 38 3; locate it on Plate 40. 4. What is the scale of 38 3? The contour interval is 250′. The altitude of the mesa is 9250′; of the plains on the north (beyond the map), 5500′. 5. Number the contour lines. By how many feet have the plains been worn down since the lava flow of the mesa was erupted? 6. In the Sierra Nevada, California, gold is found in gravel deposits under the lava cap of Table mountain;

the narrow valleys on each side of Table mountain are much lower than the gravel deposits. (See Placerville folio, *U. S. G. S.*) 7. Draw a cross section to illustrate these features. [8. In what stage of the history of the Sierra Nevada (see Exercise V, § 5) was the lava flow of Table mountain erupted?] 9. A number of extraordinary wall-like dike ridges occur near the lower slopes of the greatly dissected volcano, Spanish peaks (about 100 mi. S. of Pikes peak), Colorado; locate this volcano on Plate 40. 10. What do the dike ridges indicate as to the stage of erosion of this volcano? (See Spanish peaks folio, *U. S. G. S.*)]

17. Now turn back to Plate 19. 1. Which lava flow of 18 4 has been completely worn away in 19 7? What was its form in 20 6? 2. Compare the NW. (lava flow) table mountain in 20 6 and 19 7. Has it changed chiefly in height or in area? Why? 3. By what forms is the NE. table mountain of 20 6 represented in 19 7? Explain the change. 4. In what part of the SW. table mountain has a similar change occurred? 5. How can the terms *headward erosion* or *retrogressive erosion* be used in this connection? 6. Why has the retreat of the lava cliffs by sapping been greater than the deepening of the valleys by river erosion, in the change from 20 6 to 19 7? 7. In a still later stage of erosion, which of the volcanic features of 19 7 would disappear? which would remain? Explain. [8. About how many square miles of surface are covered with lava flows in 18 4? in 19 7? (Draw on the tracing paper, already used and placed as before, a series of lines parallel to the S. baseline, through the half-mile points on the W. baseline; another series parallel to the W. baseline, through the half-mile points on the S. baseline. What is the area of each "diamond" thus marked? Place the tracing paper on 18 4 and 19 7 and estimate the desired areas.) 9. About what fraction of the original lava-flow areas remains in 19 7?]

18. 1. In 19 8, what is the altitude of the central neck of the great volcano? 2. Estimate the altitude of the radiating ridges in the E. center of the district, and compare their altitude with

that of the corresponding part of the upland in 17 1. 3. How completely has the great volcano been worn away? What parts of it remain? Why might these parts be spoken of as the "roots"? 4. How many necks and dikes are shown? To what are they related in the earlier figures of this series? Why are they better shown in 19 8 than in 20 5 or 20 6? 5. What forms are now seen where the table mountains of 20 6 and 19 7 stood? Explain. 6. Why may 19 8 be described as a district of "lost volcanoes"? [7. Add a profile to 15 14 showing the three necks as they appear in 19 8.] [8. Several large knobs or necks of volcanic rock (lava) occur in the St. Lawrence valley; one of them gives name to the chief city of Canada. (*DP*, 217.1.) Volcanic necks are not uncommon in S. Scotland. No "table mountains" occur in either of these districts. 9. What supposition may be made as to the amount of erosion that has taken place in those districts?]

19. [1. Describe in a general way the changes commonly made by volcanoes and lava flows in forming lakes; in displacing rivers to one side of their former courses; in turning part of one river across a divide to another river system. 2. What effect may volcanoes and lava flows have in shifting the point of junction of two streams? in replacing a single stream by two nearly parallel streams? in originating groups of radiating streams? 3. What is the length of river *UV* in 17 1 and in 19 8? (Lay a thread or a narrow strip of paper along the turns of the river and measure its length.) 4. Compare the fall of *UV* (feet per mile) in 17 1 and 19 8, and explain the difference. 5. Use tracing paper as before, and copy rivers *UV*, *Z*, *YY'* from 17 1. 6. Lay the tracing paper on 19 8. Why is the displacement of river *UV* in 19 8 least near the N. border of the district? Why has it been displaced westward? About how far has it been displaced in its middle course? 7. Why does a stream run W. across former mid-course of *UV*? Why do the next downstream branches of *UV* (on E. side) run away from the original course of *UV*? 8. Why does the N. part of river *YY'*, 17 1, flow to river *UV* in 19 8? Why is the original lower part of *YY'* now

represented by two streams? 9. Why is river *Z* more crooked in 19 8 than in 17 1?]

20. [1. A line about 9″ long is drawn on the side of Plate 19. Let this line represent a very long period of time. (The line may be imagined as extending indefinitely in each direction, thus representing earlier time without beginning, and later time without end.) 2. Turn the Atlas so that the line is horizontal. Mark small crosses on the line at 0, $\frac{1}{8}$, 1, and 3 inches from its left end; number these crosses 1, 3, 4, 6, and let them represent the dates of 17 1, 18 3, 18 4, and 20 6 in the series of volcanic figures here studied. 3. Indicate by other crosses, properly placed and numbered, the dates of 17 2, 20 5, 19 7, and 19 8. 4. Print F, to show the estimated date of the first volcanic eruption; L, to show the last eruption. 5. How far to the left of the first cross would you place a mark A, to indicate the date of the general uplift of the region, as a result of which the mature valleys of 17 1 were eroded? (Note that the valley SE. of the lava flows in 20 5 has a narrower floor than the corresponding valley in 17 1.) 6. How far to the right of cross 8 would you place another cross Z, to represent so late a stage in the cycle of erosion that the hills of 19 8 shall have been worn down almost flat, that is, to a peneplain? (Erosion proceeds more and more slowly as hill slopes are worn to less and less declivity.) 7. During what part of the cycle AZ did the volcanic eruptions FL occur? 8. Through (about) what fraction of the cycle did the lava flows (table mountains) endure? 9. If the whole cycle were something like 10,000,000 or 30,000,000 years long, how many years were required for building the volcanoes? for wearing away the lava flows? 10. Has the duration of the cycle of erosion been lengthened or shortened by the occurrence of volcanic action? 11. Why may the volcanic phenomena be referred to as "accidents in the normal cycle of erosion"?]

21. Define: § 2, volcano, crater, lava flow; § 3, volcanic lake, gorge, pipe; § 4, volcanic cinders, ashes, and dust; § 6, volcanic pipe and neck; § 8, dike, [malpais]; § 13, caldera, breached volcano or cone; § 15, table mountain; § 16, mesa, dike ridge.

EXERCISE VII. THE RIVER CYCLE: WATERFALLS, RAPIDS, AND GRADED RIVERS

OBJECT. **To study various problems in connection with the development of rivers.**

Preliminary. 21 1 is a block diagram of part of a lowland crossed by a number of low E.–W. ridges and drained by two S.-flowing rivers, *R* and *Q*. The lowland is so nearly level that much of the rainfall sinks into the soil or dries off from the surface; hence the number of branch streams is small. Each block is about 4 mi. wide. A scale of miles is marked along the W. baseline of the block. The shore of the ocean is shown near the S. end of the block. The dotted line on the W. block face indicates sea level; the short vertical lines rising from it show altitudes of 100′. (The vertical scale is much exaggerated.) The following figures, 21 2, 22 3 and 4, etc., illustrate later stages in the history of the same district as 21 1, as it is uplifted and dissected. This exercise uses 21, 22, 23, 24, 26, 1–12.

1. 1. What is (about) the altitude of the lowland at the N. end of 21 1? What is the fall of river *R* per mile? 2. About how high are the ridges over the lowland? 3. The lowland has a fine deep soil; the low ridges have a thin stony soil. What can you infer as to the resistance of the rocks under the low ridges, as compared to that of the rocks under the lowland? 4. In what stage of a cycle of erosion does this district seem to be? [5. Draw a N.–S. profile in 21 1 *b* across belts *E*, *D*, *C*, along the middle N.–S. line of 21 1. 6. Draw an E.–W. profile in 21 2 *b* along belt E.] 7. 21 2 shows a later stage in the history of the district. (Altitudes of 0′, 200′, 400′, and 600′ are shown by dotted lines, and the profile of 21 1 is drawn in a broken line on the W. block face of 21 2.) 8. Compare

the altitudes of 21 1 and 21 2 in the NE. corner; NW. corner; at W. and E. ends of belt *L*; of belt *H*; of belt *E*; along the shore line of 21 1. 9. Has the district been evenly or unevenly uplifted? 10. Why do lakes *S* and *T* occur? NOTE: It is not usual to find lakes produced by uneven uplift or *warping* of the earth's crust, because the basins thus formed are usually filled with inwashed waste (as well as cut down at the point of river overflow) while the warping goes on. 11. What may be inferred from this as to the rate at which warping usually takes place? [12. What other illustration of the rate of crustal warping have you had in these exercises?]

2. 1. Where has the waste from the head waters of rivers *R* and *Q*, 21 2, been deposited? 2. Why may lakes be regarded as "river filters"? 3. Mark [blue] the shore line that lake *T* would have had if the head streams of *Q* had not formed a delta in it. 4. About how much has the outlet of lake *T* been cut down in ridge *J*? 5. Draw a broken [blue] line to show the shore line that you think lake *T* would have had if its outlet had not been cut down by stream *Q* in ridge *J*. 6. Why is the delta in lake *S* larger than the delta in lake *T*? 7. If *R* had been a much larger river than it is, what effect might it have had on the occurrence of a lake in basin *S*? [8. Compare the altitudes of the W. part of ridge *J*, lake *S*, and the land between lakes *S* and *T*. 9. Where would the outlet (overflow) of lake *S* be, if river *R* had not been able to cut a notch in ridge *J* during the warping of the district? 10. Compare the direction of general land slope in 21 1 with the direction of land slope from ridge *J* to lake *S* in 21 2. 11. Why was river *R* not turned eastward to lake *T* while this local northward slope was upwarped across its course? 12. What name is given to rivers of this class? (Exercise V, § 9.) 13. In what part of their courses are rivers *R* and *Q* antecedent?]

3. 1. Determine the average fall in 21 2 of river *R* from the notch in ridge *J* (altitude, 400′) to the sea, and compare it with the average fall of *R* in 21 1. 2. What effect has the increase of fall had

on the behavior of the river? 3. What term may be applied to rivers whose activity is thus increased? (Exercise V, § 5.) 4. How many waterfalls occur on *R* in 21 2? 5. Does the location of the four larger falls on *R* confirm the inference already made (§ 1, question 3) as to the occurrence of resistant rocks under the low ridges of 21 1? Explain. 6. How are the waterfalls related to the resistant and weak rocks? (*DE*, 252.2; *DP*, 236.1; *G*, 38.8; *T*, 54.1.) 7. How may the six small falls on river *R*, 21 2 (marked by short lines across the river), in the weaker rocks *B*, *D*, *F*, *H*, be accounted for? 8. In what parts of a district like 21 2 would you look to find the attitude (horizontal, slanting upstream or downstream, vertical) of the rock layers? 9. What is the attitude of the rock layers in 22 3 *c*? in 22 4 *a*? 10. To what parts of 21 2 might the larger-scale 22 3 *c* correspond? [11. Draw a [red] line in 22 3 *c*, separating the resistant strata from the weaker strata.] NOTE: The steep walls of a river gorge show many rock outcrops from which the structure of the district may be determined. 12. How is the structure of the district here studied represented on the W. block-face of the figures in this exercise? 13. What is the general attitude of the groups of strata, or *formations*, there represented?

4. 1. What determines the depth to which the valley of river *R*, 21 2, has been eroded upstream from formation *J*? 2. Why may the notch in each resistant formation be regarded as the *local base-level* with respect to which the next upstream weaker formation is worn down? 3. Why is the valley of river *R*, 21 2, deeper in formation *B* than in formation *K*? 4. Why are the falls from formation *J* higher than from formation *G*? 5. A river flowing through a narrow gorge usually has certain parts of even flow (*reaches*), certain parts of hurried, uneven flow (*rapids*), and certain parts of steep or vertical plunge (*falls*). 6. Mark in 22 3 *c* and 22 4 *a* a full [blue] line on the reaches, a broken [blue] line on the rapids, and a dotted [blue] line on the falls. 7. How are reaches, rapids, and falls related to the occurrence of resistant and weak formations? 8. How many reaches separated by how many falls occur on river

R, 21 2? (The rapids in the notches are too small to be shown in this figure; they are indicated in 22 3 *c*.) [9. Draw in 21 1 *c* a N.–S. profile across belts *E*, *D*, *C*, as they are seen on the W. border of 21 2; and in 21 1 *d*, a profile across the same belts along river *R*, 21 2. 10. Indicate the underground structure beneath these profiles. 11. Draw in 21 2 *c* an E.–W. profile along belt *E*, 21 2; and in 21 2 *d*, an E.–W. profile along belt *D*; add lines to the last profile to represent the side streams in belt *D*.]

5. NOTE: 22 3 shows a greater amount of up-warping than 21 2. (The profiles of 21 1 and 21 2 are marked in broken lines on the W. block-face of 22 3.) 1. About how much uplift has occurred from 21 2 to 22 3 in the N. part of the district? in the center? in the southern part? 2. What has happened in 22 3 to lakes *S* and *T* of 21 2? 3. Describe the course of river *R* as to reaches, rapids, and falls in 22 3. 4. Where has a new fall been formed? Why? 5. Where have some small falls been destroyed? How and why? 6. How are the reaches, formerly separated by the small falls, now related? 7. Compare the height of the falls from *C* and *E* (the *C* and *E* falls) in 21 2 and 22 3. 8. Why have the falls decreased in height at one place, and increased at the other? [9. Answer similar questions for the *G* and *J* falls.] 10. Why is the valley of *R* deeper in formation *B* than in formation *M*? in *D* than in *F*? in *H* than in *F*? 11. Why is the valley of *Q* in general less deep than the valley of *R*? [12. Draw E.–W. profiles in 22 3 *ab* on belts *J* and *H*, 22 3.]

6. 1. Compare the altitudes of *E*, *J*, and *L* on the W. profile of 22 3 and 22 4. 2. Has 22 4 been uplifted as compared with 22 3? 3. What general change has taken place in the depth of the *R* and *Q* valleys? in their width? 4. Has the number of falls on *R* changed? Explain. 5. Has the number of reaches changed? Explain. 6. The uppermost line of 26 9 shows the profile of the W. border of the upland of 22 3. (The vertical scale is here exaggerated over the horizontal about 16 times.) The line in 26 9 marked 3, 3, 3 shows part of the profile of river *R* for 22 3. 7. Complete the profile in

formations *D* and *B*. 8. Several short lines marked 4 indicate parts of the profile of *R* in 22 4. Complete this profile. 9. Compare the number of falls and reaches in 22 4 (or profile 4) and in 21 2. 10. What change has taken place in the number of falls? in the number and length of the reaches? Explain. 11. What would you expect as to the number and length of separate reaches at an earlier stage of gorge erosion than 21 2? at a later stage than 22 4? Explain. 12. On what sort of strata are the falls earliest worn down? latest worn down? 13. On what sort of strata are uninterrupted reaches soonest developed? 14. How may the term *grade* be used in this connection? (See Exercise III, § 4; *DE*, 254.4; *DP*, 237.5; *T*, 56.8.) [NOTE: Several streams in NE. Pennsylvania flow across an inclined series of strong and weak formations. Waterfalls occur where the streams pass from the strong to the weak formations. 15. Which figure in Plate 22 gives best illustration of these falls? 16. Explain their origin. 17. Where do graded reaches probably occur on these streams?]

7. 1. Draw in 26 9, through the lines marked 5, the profile of *R* for 23 5. 2. Which falls are now almost reduced to rapids? Why? 3. Draw profile 6 in 26 9. 4. Why have the *E* falls decreased in height? 5. Why are the *C* and *G* rapids almost obliterated? 6. Compare the amount of erosion on *C* and *L* between profiles 5 and 6. Which has been eroded by the greater amount? Why? 7. Why have the *C* falls been decreased and the *L* falls been increased in height during this interval? 8. Draw profiles 7 and 8 in 26 9. 9. Compare profiles 3 and 8 as to number of falls; height of falls; number and length of reaches. 10. Why are the *J* rapids longer but less steep in profile 8 than in profile 3? [11. Examine the upper profile of 24 8 *a*. Are the resistant formations odd-numbered or even-numbered? 12. Complete the river profiles *m*, *m* and *n*, *n*. 13. Draw some additional river profiles. 14. Which fall-making formations will have been worn downward (nearly vertically) when their falls are extinguished (or obliterated)? Which will have been worn backward (upstream nearly horizontally)?

Why? 15. Examine the river profiles in 24 7 *a*, *b*, *c*. What is the attitude of the strata in each figure? 16. Print F on each fall-making formation. 17. Let the lower broken line in each figure represent the profile that the river will have when it is graded across the fall maker (as in profile 8, of 26 9); prolong this graded profile upstream. 18. In which figure must the fall maker be eroded by the greatest amount before the fall is obliterated? by the least amount? Why?] [19. Several rivers flowing E. from the highlands of the Transvaal, S. Africa (locate on Plate 45), have worn deep valleys across inclined strata (slanting W.). To what ocean do these rivers flow? Elands river, in the S. part of Portuguese East Africa, still has two falls where it crosses the most resistant formations of its course. With which falls in 23 5 do these two falls correspond? 20. The Potomac river has eroded a deep, narrow notch in the inclined, resistant strata of the Blue ridge at Harpers Ferry; there the river flows in shallow rapids across the edges of the rock layers. Locate Harpers Ferry in relation to the neighboring states. (See Plate 40.) What effect have the rapids on the navigation of the Potomac? 21. On what formation are similar rapids shown in 24 7?]

8. [1. Compare the position of the falls on formations *C* and *L* in profiles 3, 5, and 8 of 26 9, as to distance from river mouth. (Measure the distances on the scale of miles at base of 26 9; the forward growth of *R* delta in the sea may be neglected in this connection.) 2. Why are the falls or rapids on these formations farther from the river mouth in profile 5 than in profile 3? 3. Why has the increase of distance from river mouth in the *L* falls been greater than in the *C* falls? 4. Why may the *L* falls be described as having been *worn back*, or as having *retreated*, while those from *C* have been mostly *worn down*? 5. How far have the *L* falls retreated between profiles 6 and 8?] [6. Compare the slope of the graded reaches in profiles 3 and 8 of 26 9. Explain the difference. (Consider in this connection the amount of waste received by the river from its valley sides and its side streams in these two stages.

Examine 22 3 and 24 8.) 7. If the N. extension of formation *L* be horizontal, how far must its waterfall retreat before it is *obliterated* or *extinguished* (the grade of the river remaining as in profile 8 of 26 9)? 8. Suppose that, during the retreat of the *L* falls, the rapids on *J* are worn down lower than profile 8; what effect will this have on the retreat needed for the obliteration of the *L* falls? 9. Suppose that, during the retreat of the *L* falls and the reduction of the *J* rapids, the slope of the graded reaches in river *R* is lessened (because the load to be carried is lessened); what effect will this have on the amount of retreat of the *L* falls before they are obliterated? 10. Which are longer lasting, falls from vertical, from inclined, or from horizontal strata of the same resistance?]

9. [1. Assume the amount of water that is discharged by river *R* to be the same in all the chief figures of this exercise. Does the river flow faster in 21 1 or 22 3? 2. Then in which figure, 21 1 or 22 3, should the river be broader? (If a slow-flowing and a fast-flowing river discharge the same amount of water, the fast-flowing river will be narrower than the other. Explain.) 3. In what part of the river in 22 3 would you expect it to be narrowest? broadest? (See 21 2 *a*, 22 3 *c*, and 22 4 *a*.) Why? 4. In what part deepest? shallowest? (The plunge of a large river from high falls scours out a deep pool in the weak strata below the falls; the rush of flood waters wears the weak strata of graded reaches somewhat deeper than the hard strata of rapids.) 5. If river *R* should cease running in a dry season, where would pools remain in its channel? 6. What sort of a lake is shown near the S. part of river *R* in 24 8? Compare it as to origin, size, and stage of river development with the two lakes of 21 2. 7. In which of the chief figures of the exercise would river *R* be most easily followed by boats or rafts? 8. If an Indian came down river *R* of 23 5 in a canoe, how many "carries" would he have to make? (A carry or portage must be made where the falls or rapids are so steep that the canoe has to be carried along the river bank.)]

10. 1. The occurrence of many falls and rapids in the course of a river indicate that it is in an early stage of development; the river is then young. As the falls and rapids are obliterated and the separate reaches unite in a long-continuous graded course, the river is mature. When the valley floor has been widened and the graded course worn down to a very gentle slope, the river is old. 2. In which of the chief figures of this exercise is river *R* young? in which one is it mature? old? [3. Other indications of the stage of development of a river are to be found in its velocity, in the quantity and texture of its load, in the breadth of its flood plain, etc. 4. State some of these indications.] 5. Through what changes do you think *R* had passed before it reached the condition shown in 21 1? [6. Let the chief figures of this exercise illustrate a "cycle of river development," in which the stages of 21 1, 22 3, 23 6, and 24 8 are indicated by corresponding numbers over the time line of 26 10. 7. Add other numbers to show the stages of 21 2, 22 4, 23 5, and 24 7. 8. Print PERIOD OF UPLIFT under the proper part of the time line. 9. With what stage of river development is the period of uplift associated? Why? 10. Are the processes of erosion more active on the steep slopes of youth or on the faint slopes of old age? 11. In view of this, about how far to the right of stage 8 in 26 10 should a ninth stage, with slopes and relief as small as in 21 1, be placed? 12. Which is of longer duration, youth, maturity, or old age of a river? 13. What stage of river development had been reached in the cycle during which 21 1 was developed, when it was interrupted by the warping uplift which introduced the cycle here studied?]

11. Define: § 3, formation; § 4, local baselevel, reach, rapids, falls; § 6, grade; § 8, retreating waterfalls, worn-down waterfalls, obliterated waterfalls; [§ 9, portage or carry;] § 10, cycle of river development, youth, maturity, and old age of a river.

EXERCISE VIII. THE RIVER CYCLE: RIDGES, VALLEYS, AND RIVER CAPTURES

OBJECT. **To study the origin of longitudinal ridges and valleys, and the rearrangement of river courses associated with these features.**

Preliminary. The figures used in the previous exercise serve for this exercise also.

1. 1. In 21 2, why are the notches cut by rivers *R* and *Q* in the harder formations *C*, *E*, etc., V-shaped, instead of having vertical walls? 2. Draw a [red] line along the top of the valley sides of rivers *R* and *Q* in formations *E*, *F*, and *G*. (Neglect the E. and W. side ravines for the present.) [3. 21 1 *a* is a contour map of belts *E*, *F*, *G*; complete the contours W. of river *R*. 4. 21 2 *a* is a hachure map of belts *C*, *D*, *E*; complete the hachures W. of river *R*. Mark a [red] line in 21 2 *a* along the top of the valley sides of valleys *R* and *Q*.] 5. In which belts is valley *R* wider (at level of upland)? In which belts is it narrower? 6. Why does its width vary? 7. Make a general rule, stating the relation between the width of a young valley and the resistance of the formations in which it is eroded. 8. By how many instances is this rule supported in 21 2? 9. If the valley of river *R* is wider in formation *F* than in formation *E*, why is it not also eroded to a lower level in *F* than in *E*? 10. Examine the *R* valley in 22 3 and 4 with regard to the relation between rock resistance and valley form, and then complete the following statement: The *width* of a young valley that is eroded across a weak formation is independent of, and is usually greater than, the *width* of the valley notches eroded in neighboring strong formations; but the *depth* to which a young valley can be eroded across a weak formation . . . 11. What effect has the revival of *R* and *Q* had on their branch streams?

12. Do the branches join the main rivers in accordant or in hanging fashion? Why?

2. 1. In 22 3 draw a light [red] line along the divide between the drainage areas of rivers *R* and *Q*. Why may the divide be called *ill defined?* 2. Compare the cross (E.–W.) profiles of *R* valley in formation *J*, 21 2 and 22 3. [Complete the profiles in 21 2 *c* and 22 3 *a*.] Do the same for *R* valley in formation *H*. [Complete the profiles in 21 2 *d* and 23 3 *b*.] Explain the changes. 3. Complete in 22 4 *b* the E.–W. profiles on formations *H* and *J*, 22 4. (See J^4 and H^4.) 4. How have they changed from the corresponding profiles for 22 3 (J^3 and H^3 in 22 4 *b*)? 5. In 22 4, how many side streams join river *R* from the east in formation *H*? How many join river *Q* from the east in formation *K*? 6. Draw a light [red] line along the divide between the drainage areas of rivers *R* and *Q* in 22 4; make the line heavier on the well-defined parts of the divide than on the rest. 7. Why are some parts of the divide better defined than others? 8. Why are the head-water ravines of river *Q* longer in 22 3 than in 21 2? (Use the terms *headward erosion* or *retrogressive erosion* in answering the preceding question.) 9. Why does (most of) the divide between the two head branches of river *Q* follow a sharp-crested, notched (serrate) ridge, while the divide between rivers *Q* and *R* on formation *M* lies on a smooth-sloping upland?

3. 1. Draw in 23 5 a [red] line along the divide between rivers *R* and *Q*. 2. What parts of the divide are still ill defined? Why? 3. 23 5 *b* shows (on a somewhat larger scale) unfinished E.–W. profiles across the divide on formation *H* for several stages of this exercise. Complete the profile for stage 5. Is the divide definite or indefinite? 4. Which part (E. or W.) of formation *H* was most uplifted in 22 3? 5. Then why is river *R* at a lower level than river *Q* in stage 5, 23 5 *b*? 6. Why is the divide not halfway between *R* and *Q*? 7. At a stage of erosion between the stages of 23 5 and 23 6 the channels of rivers *R* and *Q* in formation *H* are shown on line 5-6 in 23 5 *b*. Why has *R* deepened its valley more than *Q*? 8. Complete the E.–W. profile for the stage between stages 5 and 6. 9. How has

the divide (in 23 5 *b*) between *R* and *Q* been changed as to form? as to altitude? 10. How has it been shifted with respect to *R* and *Q*? 11. Which river (*R* or *Q*) is gaining and which is losing drainage area in formation *H*? Why? 12. Which side streams (of *R* or of *Q*) are most effective in shifting (by headward erosion) the position of the divide? 13. What advantage have these side streams, that makes them more effective? 14. How does the length of the side streams change as the divide *shifts* or *migrates?* 15. Fill in the blanks in the following statement: When a smooth lowland is uplifted the ..... divides between the ..... rivers are gradually made ..... by the ..... erosion of the side streams; and then as the ..... divides are slowly ..... they are also slowly ..... toward the ..... rivers; and thus the ..... rivers slowly gain a larger drainage area. 16. Mark a [blue] *plus* sign (+) in 23 5 at several points where river *R* has recently gained drainage area by the shifting of the *R*–*Q* divide; and a [red] *minus* sign (−) at points where *Q* is losing drainage area.

4. 1. With what part of 23 5 does the enlarged sketch in 26 11 correspond? 2. What river receives the drainage from surfaces *b*, *b*, 26 11? from surfaces *a*, *a*? 3. Draw a [red] line in 26 11 along the divide between the side branches of *Q* and *R* (*R* is not shown). 4. What is the general altitude of the foreground lowland (*a*) on formation *H*? of the same formation near river *Q*? 5. What has caused this difference in altitude? 6. What effect will continued erosion have on the length of streams h^1 and h^2? on the position of the *R*–*Q* divide? 7. Draw a broken [red] line to show the *R*–*Q* divide at a somewhat later stage (when its distance from river *Q* is halved). 8. Draw in 23 5 *b* an E.–W. profile for the same later stage (between stages 5–6 and 6). 9. If changes of this kind go on, what will happen to river *Q*? 10. Draw a [blue] line in 26 11 to show what you expect. 11. Illustrate the same change by drawing a new profile in 23 5 *b*. 12. Why may the expected change be described as *river capture* or *river diversion?* NOTE: As the divide is shifted close to river *Q*, more and more of its water

will pass underground and enlarge the springs that feed the head waters of streams h^1, 26 11. 13. When the expected change has happened, which river may be called *captured* or *diverted?* Which stream may be called the *diverter?* 14. Why may the lower part of river Q then be described as *beheaded?* (See Q', 26 12.) 15. How will the volume of the beheaded river be affected? 16. To what river will the upper part of river Q (see Q'', 26 12) then flow?

5. 1. Draw a [red] line in 26 12 and 23 6 along the divide between rivers R and Q'. 2. In what important respect has the divide been changed from the divide in 26 11 and 23 5? 3. Has the greatest part of this change taken place slowly or (relatively) rapidly? 4. If the shifting or migration of the divide between stages 4, 5, and 5–6, in 23 5 *b*, be described as *creeping*, what part of the shifting may be described as *leaping?* 5. Why may the point where the capture was made be called the *elbow of capture?* 6. Print W at this point in 26 12. 7. Why has river Q''–h^1 deepened its valley downstream from the elbow of capture? and also upstream from the elbow? 8. Why is the valley of Q'' in formation K not deepened in 26 12? 9. Which waterfall is higher as a result of this river capture? 10. What has happened in 26 12 (since the leaping of the divide around the upper part of river Q) as to erosion along stream h^2? along streams h^3 and h^4? 11. Explain these happenings. 12. What changes may be expected to take place (in the not distant future) in stream h^5? in stream h^6? 13. What part of these last changes is made by creeping? by leaping? What is the relative importance of creeping and leaping in these changes of the divide? 14. What change will take place at the same time in the volume of the G waterfall of stream Q'? in the volume of h^1? 15. Draw in 26 12 broken [blue] lines to show the future courses of streams h^5 and h^6; a broken [red] line to show the divide between Q''–h^1 and Q', when these changes have gone on as far as they can. 16. 23 5 *a* shows on a larger scale a part of river Q, on formation F of 23 5. Compare the size of the stream curves with the size of the valley curves. How have the

valley curves been produced? 17. 23 6 *b* shows the same district for 23 6. Compare the valley curves in 23 5 *a* and 6 *b*; the stream curves. 18. Explain the changes. 19. Why may the stream of 23 6 *b* be described as a *misfit* for its valley?

6. 1. At what other points in 23 6 may stream captures take place in the future? 2. How many captures (besides the one shown in 23 6) have taken place during the development of 24 7? 3. Print W at all the "elbows of capture" that you can find in 24 7. 4. Print X at points of capture where "no elbow" was made (as will be the case with streams h^5 and h^6, 26 12). 5. Draw a [red] line in 24 7 along the divide between the drainage areas of rivers *R* and *Q'*. 6. What other capture may be predicted? 7. Draw a broken [red] line along the divide between *R* and *Q'*, 24 8. 8. What other capture may still be expected? 9. Draw a full [red] line along the *R*–*Q'* divide after this capture has happened. 10. Compare in 22 3 and 24 8 the drainage area of river *R*; the length of the eastern branches of river *R*; the number of notches in which streams run through hard-rock ridges. 11. Explain (briefly) the changes. NOTE: When a stream runs through a notch or "gap" in a ridge, the notch may be called a *water gap;* when no stream runs through the notch, it may be called a *wind gap.* 12. Print T at the water gaps and N at the wind gaps in 24 7. 13. What is the origin of the chief wind gaps? 14. Compare in 22 4 and 24 8 the sharpness of the divides (or "subdivides") between the branch streams; for example, the subdivides of the E. branches of *R* on formations *A* and *B*. 15. In view of this comparison, what additional statement regarding divides may be made, following that of § 3, question 15? NOTE: In 21 1 the drainage (by rivers *R* and *Q*) is chiefly transverse (at right angles to the general trend of the ridges); in 24 8 there is only one long transverse river, and the rest of the streams are for the most part longitudinal (parallel to the trend of the ridges). 16. Explain (briefly) how the change from transverse to longitudinal drainage has been brought about. 17. Of the two originally transverse rivers, *R* and *Q*, 21 1, why

has *R* survived? [18. A stream which increases in length by headward erosion along a belt of weak strata may be classed as *subsequent*. 19. Mark S by several subsequent streams in 24 7 or 24 8. 20. Why do no longitudinal streams run along the resistant formations?] [21. The Allegheny mountains of Pennsylvania and Virginia offer many examples of longitudinal and transverse drainage, similar to that of 23 6, 24 7, and 24 8. 22. Locate 38 1 on Plate 40. What river is there shown? Is its course longitudinal or transverse? 23. How many longitudinal streams are shown? To what class do they belong? 24. The lowest contour line is 400′; the contour interval is 100′. Print altitude numbers on the contour lines, beginning at the middle of the S. border and passing N. to the N. border. 25. How deep are the valleys below the ridge crests?]

7. 1. Compare the hard-rock ridges in 21 1 and 23 5 as to altitude; as to relief. 2. What has caused the change in altitude? in relief? 3. Which change has made the other change possible? [4. Draw a N.–S. profile across belts *C* to *G* of 24 8 in 23 6 *c*; draw the same profile at a still later stage of erosion.] 5. Compare the ridges of 23 5 and 24 8 as to altitude; as to relief. 6. What has caused the change in altitude? in relief? [7. In 23 6 *a* the uppermost profile shows the form of ridges *E* and *C*, and of the intermediate valley *D* for 23 5, about a mile E. of river *R*; complete the profiles for 23 6 and 24 7. 8. Draw earlier profiles for stages 21 2, 22 3 and 4.] 9. Explain (briefly) how the wider parts (on the weaker formations) of the *transverse valley R* in 21 2 and 22 3 have grown into *longitudinal valleys* in 23 6, 24 7 and 8. 10. How is the altitude of a longitudinal valley floor related to the altitude of the next downstream water gap in the inclosing longitudinal ridge? Explain. 11. How are the altitudes of several neighboring longitudinal valley floors of the same river system (as *D*, *F*, *H*, *K*, 24 7) related to each other? Explain. 12. Is there a corresponding relation in the altitudes of the several longitudinal ridges (as *E*, *G*, *J*, 24 7) between the longitudinal valleys? Explain. [13. Complete

ridge-and-valley profile *k*, 24 8 *a*. Draw an earlier ridge-and-valley profile corresponding to stream profile *n*; draw a later profile.]

8. [1. 38 1 shows several longitudinal ridges and valleys. In what part of what state are they? To what mountains do they belong? 2. How high are the ridges? (See § 6, question 25.) 3. Are the ridge crests even or serrate (sawlike)? 4. How many belts of strong and weak strata are here included? 5. What is the origin of the notches in the ridges? 6. What is the origin of the longitudinal valleys? 7. Which figure of this exercise, Plates 21–24, most nearly exhibits the features of 38 1? 8. What general explanation can you give for the ridges, valleys, and notches of the Allegheny mountains? 9. A fertile longitudinal valley in Virginia (Shenandoah valley) lies next NW. of the Blue ridge, and is drained through the transverse notch or gap eroded by the Potomac river in the Blue ridge: Explain the origin of the longitudinal valley in relation to the Blue ridge and the Potomac gap.]

9. [1. What is the attitude (vertical, steep slanting, gently slanting) of the ridge-making formation in 24 7 *d*? in 7 *e*? in 7 *f*? 2. Draw in these figures a [red] profile for each ridge after its height is reduced by half (the level of the neighboring longitudinal valleys remaining little changed). 3. In which figure has the ridge crest changed its position (to right or left) by the greatest distance? by the least distance? Why? 4. Draw a broken [red] line along the ridge crests *C*, *G*, *L* in 23 5 and 6, 24 7 and 8. 5. Why may these lines be called *longitudinal divides* (or subdivides)? 6. Why do the more important longitudinal divides follow the strong formations? 7. Draw vertical lines in the same figures from the W. end of the *C*, *G*, and *L* ridge crests (or longitudinal divides) to the sea-level line (see 23 5, ridges *C* and *G*); mark off on a strip of paper the distance from the SE. corner of the block to these vertical lines. 8. As the divides are lowered, in which direction has their position been shifted? Why? 9. Which one has changed most? Why? 10. Make a general rule, showing how the shift of a wasting ridge crest is related in direction and amount to the

attitude of the ridge-making formation. 11. Compare the cause of this kind of migrating divide with that of the kind described in §§ 3 and 4.]

10. [1. In the cycle of erosion of a district made of inclined formations, resistant and weak, which of the formations will be soonest worn down to an "old" appearance (small relief, little above sea level)? 2. How much may the resistant formations be worn down after the surface form of the weak formations is "old"? 3. What will the surface form of the weak formations be, when the resistant formations are worn down to small relief? 4. In the early stages of a cycle of erosion, which are worn down the faster, the weak formations or the main river channels? Explain. Illustrate by one of the figures of this exercise. 5. In the early stages of a cycle, which formations are worn down faster, the resistant or the weak? Illustrate, as above. 6. In the late stages of a cycle, which formations are worn down the faster? Explain. Illustrate, as above. 7. In the late stages of a cycle, which are worn down faster, the resistant formations or the river channels? Explain. Illustrate, as above. 8. If you should find a lowland of tilted or disordered strata (like 21 1), in what stage of a cycle of erosion would you suppose it to be? 9. If you found a rather even highland (of disordered structure) trenched by narrow, steep-sided valleys, what stages of two cycles of erosion would be there represented? 10. What movement of the earth's crust would be supposed to have taken place after the even surface of the region had been produced? Explain.]

11. Define: § 3, shift or migration of a divide; § 4, river capture, river diversion, captured river, diverted river, diverter, beheaded river; § 5, creeping divide, leaping divide, elbow of capture, misfit stream; § 6, water gap, wind gap, subsequent stream; § 7, transverse valley, longitudinal valley; [§ 9, longitudinal divide].

EXERCISE IX. SHORE LINES

OBJECT. **To study the headlands, cliffs, bays, and other features of a hilly or mountainous coast.**

Preliminary. The series of eight maps in this exercise, on Plates 27-29, are all on the scale of 1 : 80,000. The first map, 27 1, shows a district of low mountains and hills, bordering the sea, in part shaded with hachures, in part drawn with contours (50′ interval). The small crosses (× ×) in the water area represent low rocky ledges or reefs. Depth of water (in feet) is indicated at several points. (The broken lines in the water area will be explained later.) In the E. part of the map the rocks are resistant and the mountains are late mature or subdued; in the N. part the rocks are weaker, and early old age is indicated by the low rounded hills and open lowlands. The later maps, drawn in the same style, illustrate changes due to the work of shore waves and currents, and to movements of elevation and depression. This exercise uses Plates 25, 27, 28, 29, 39.

1. 1. Suppose the land in 27 1 to sink, or the sea to rise, nearly 100′; draw a [blue] line in the contoured area, to show the new shore line thus produced. 2. What effect has the change of level on bays *A* and *B* as to size? as to general shape? on the length of the streams entering the bays? on the contoured island as to size? 3. How many headlands or peninsulas are converted into islands? Why? 4. Why are three hills, between bays *A* and *B*, converted into small low islands? 5. Where are new peninsulas formed, each connected with the mainland by a narrow isthmus? 6. Why is each isthmus narrower than its peninsula? 7. If the land had been submerged 150′, why would each of these peninsulas have become an island? each isthmus a strait (or narrow

water passage)? [8. Add contours and hachures to some of the unshaded hills and valleys in 27 1. 9. The scale being 1 : 80,000, construct a linear scale 5 mi. long in the lower part of 27 1.]

2. 1. Suppose the land in 27 1 to rise, or the sea to sink, about 70′; mark in the SE. part of the map a dotted [blue] line to show (as well as you can) the new shore line. (This new line may be drawn about $\frac{1}{4}''$ from the present shore line.) 2. What effect is thus produced on the length of the headlands? of the bays? of the streams? on the breadth of the isthmus between bays *C* and *D*? 3. Why are two islands converted into peninsulas? two straits into isthmuses? some rocky reefs added to the mainland? 4. Suppose the land in 27 1 once to have stood 200′ higher (or the sea 200′ lower) than now; only a small space in the SW. corner of the map would then have been under the sea. 5. Draw in broken [blue] lines (see the broken guide-lines in 27 1) the extended rivers along the troughs of the bays. 6. Which river, *A*, *B*, *C*, or *D*, was largest? [7. Draw (roughly) the 50′, 100′, and 150′ contours for the valley of river *AB*.] 8. In view of all this, explain the origin of the shore line, as it is drawn in 27 1. [9. State the stage — young, mature, or old — reached in the cycle of erosion before the change of level which produced the present shore line; the nature of the change of level (rising or sinking of land). 10. Estimate the amount of the change.]

3. 1. In the change of level by which the shore line of 27 1 was produced, what preëxistent forms have been changed into large bays? into small bays (or coves)? wide bays? narrow bays? headlands? peninsulas? isthmuses? straits? islands? rocky reefs? 2. Why was river *C* more shortened than rivers *A*, *B*, or *D*? 3. Why may the various rivers and streams as drawn in 27 1 be described as *dismembered by submergence?* 4. Why may such a coast be classed as *embayed?* 5. Why may such a district be described as *partly drowned?* 6. Why do the dismembered streams all flow into bay heads? 7. Draw a [red] line along the divide between bays *C* and *D*; between bays *A* and *B*. Why do these

divides run to headlands? 8. Why are some headlands round (as on NW. side of bay *C*)? and some sharp (either side of bay *D*)?

4. 1. During the slow submergence (hundreds of thousands of years) by which a coastal district is more or less drowned and an embayed shore line is produced, the shore waves attack the sinking land, sweeping away the previously weathered soil and loosened rock. 2. When the submergence has ceased, the attack of the waves continues at the level then reached. 3. The attack is especially strong on the more exposed parts of the coast. Why? 4. What new features will be thus carved? (*DE*, 310.7; *DP*, 360.7; *G*, 309.9; *T*, 211.3.) 5. Draw a [red] line in 27 1 close along the shore where small features of this kind have already been produced. (See the darker, ragged parts of the shore line.) 6. What features will in time be produced by the streams at the bay heads? [7. Has the land stood in its present position as long as it stood in its former position (before submergence)? Explain.] [8. In what part of what state is the coast shown in 39 1? To what class does this coast belong? What is its origin? 9. Mark a [red] line across three isthmuses. 10. The rocks of this district are in great disorder. In what stage of erosion was the district just before submergence took place? 11. Why are some of the bays called harbors? Which strait is called a river? Which upper bay is called a river? 12. Draw a [blue] line through each of three straits. What would these lines have represented before the submergence of the region? 13. If the submergence had been almost 100′ greater, into how many islands would Southport (island) have been divided? Draw its shore line [blue] in that condition. 14. Draw [in blue] as well as you can the stream system of Booth-bay harbor before submergence.]

5. 1. 25 1 is a block diagram (larger scale and more detailed than 27 1) showing a low *sea cliff BE*, and a *rock bench EC*, cut by strong waves on a sloping coast, like that SE. of bay *D*, 27 1. 2. What different conditions of tide and weather are shown in the three parts of 25 1? (*DE*, 119.8; *DP*, 83.4; *G*, 290.2; *T*, 187.3.)

3. About how high is the cliff (see scale at right corner)? 4. What is the tidal range (in feet) here indicated? 5. How wide is the rock bench *EC* between the cliff base and the low-water shore line? 6. What is the relation of the sea level at high tide to the cliff? [7. Prolong the profile line *AB* to low-water level a little outside of *C*; from the intersection of the profile and the low-water line draw a [red] line (about parallel to the block front, outside of the rock bench) to show the *initial shore line* (as if the sea had not cut any cliff in the land slope). 8. Which is the more irregular, the initial shore line or the present shore line? Explain.] 9. Why is there so little rock waste at the base of the sea cliff? 10. Where has much of the coarser waste been deposited? 11. Where has most of the fine waste been deposited? NOTE: On the narrow, wave-cut rock bench of a bold, exposed coast, little rock waste is carried by waves and currents *along* the shore, because the waste is soon swept off into comparatively deep water. 12. In calm weather the sea water on a rocky coast is very clear. Why does it become somewhat turbid in stormy weather? [13. Explain the origin of the two *sea caves* in the cliff of the low-tide part of 251; of the *rock arch* in the high-tide part; of the little *cove* (just beyond the rock arch); of the narrow *chasm* (this side of the rock arch); of the outstanding *stack* (in the farther part, showing storm waves); of the *skerries* (small rocks or minute islands in the high-tide part); of the heap of rock waste (where high-tide and low-tide parts join).] 14. Where is the rock structure indicated? Is it horizontal or disordered? 15. Why may the district of which 251 is a part be described as "well-subdued mountains with a very *young shore line*." 16. What change will the sea cliff suffer if the storm waves continue to cut away its base?

6. 1. Draw, on the near end of 251, a profile at *M*, parallel to *BE*, to show the position of the sea cliff after it has been worn farther back. 2. From the base of cliff *M* draw a rock-bench profile parallel to *EC*. [3. How high is the new cliff *M*? How wide is its rock bench? How far has cliff *M* retreated from cliff *B*?

4. Indicate between *C* and *D* a new deposit of rock waste (about as much as is shown at *D*). 5. What effect has this deposit on the depth of the water between *C* and *D*? NOTE: During storms the loose material on the sea bottom is agitated at depths of 100′ or more. 6. What effect will this agitation have on the texture of the sea-bottom waste? 7. What will become of the "grindings"?] 8. Draw the profile for the cliff, bench, and bottom deposit for point *N*? 9. As the cliff is cut back, what change takes place in its height? in the width of the rock bench? 10. What effect will the new height of the cliff have on the amount of rock waste weathered from it? 11. What effect will the new width of the bench have on the strength of the waves at the cliff base? NOTE: As these changes go on along the shore, there comes a time when so much waste is supplied from the weather-beaten cliffs that it cannot all be quickly swept away into deeper water by the weakened waves; a sheet of coarse and fine waste thus comes to spread over more or less of the rock bench. That part of the waste sheet which is bare at low tide is called a *beach*.

7. 1. 25 2 is a general view of a shore line on a smaller scale than 25 1, but on a larger scale than 27 1. 2. How high is the cliff *QR* in 25 2? How wide is the beach-covered rock bench *RL*? How thick is the beach deposit at *L*? 3. Does 25 2 represent a more or a less advanced stage of shore development than 25 1? Explain. 4. The rock bench is now so wide that some of the beach material (cobbles, gravel, sand), when agitated by storm waves, is slowly shifted along shore by the local current. 5. Does the beach material come from the shore cliffs or from the inland valleys? Explain. 6. In which direction in 25 2 has the beach material been shifted? How can you tell? 7. Why may *ST* be described as a *barrier beach* (or *sand and gravel reef*) inclosing part of an initial embayment? 8. Has the barrier beach (or reef) been built up from the bottom or forward from one end? (See 25 3, a cross section showing lines of reef growth.) [9. In which part of the barrier beach is it thickest? 10. How deep was the water originally at

the mid-point of the reef? (Join the hill slopes *QS* and *UT* by a curved line to show the original depth of the bay between the hills; estimate the depth of the curve below the high-tide shore line.) NOTE: The height of the reef is increased by the action of storm waves, which may throw up cobbles and pebbles in a ridge 10′ or 20′ above high tide. 11. Estimate the thickness of the reef *ST* at its middle.]

8. 1. At which end of the reef *ST* in 25 2 is a passage or *inlet* kept open? 2. What does the position of the inlet indicate as to the general direction of the longshore currents? 3. In what direction will a tidal current flow through the inlet while the tide is slowly "falling" on (withdrawing from) the beach? while the tide is slowly "rising" (advancing) on the beach? 4. What name is given to these tidal currents? For about how many hours does each current run? (*DE*, 119.9; *DP*, 83.8; *T*, 187.7.) 5. What sort of material will be carried into the inclosed bay or *lagoon* by the inflowing current when the sea water is turbid during storms? 6. What will become of this material in the quiet water of the lagoon? 7. What effect will be thus produced on the size of the lagoon? NOTE: A deposit of fine silt, mixed with decaying plant material, is formed on the bottom and around the border of a lagoon; when it is built up to high-tide level and has salt grass growing on it, it is called a *tide marsh*. 8. Shade [light red] the sand and gravel reef *ST*, and [light blue] the lagoon *A*; dot [blue] the tide marsh *TM*. 9. Draw a [blue] line around the original shore of the inclosed bay; prolong this line seaward from *S* and *T*. 10. Draw a similar [blue] line around the original shore of bay *B*; draw a [blue] line to indicate the original shore line of hill *U*. (See the dotted line, showing the original sea bottom, in front section.) 11. How was the original shore line produced? [12. In what stage of erosion was the region before the original shore line was thus formed?]

9. 1. When a reef extends only part way across a bay, it is called a *spit*. Where is a spit shown in 25 2? Why may it be

called a *hooked spit*? 2. Does much waste from cliff *U* now go to the beach of cliff *X*? from cliff *Q* to the spit of bay *B*? (Beach material may be swept past a narrow tidal inlet on the shallow bottom formed by the extension of the beach material offshore.) [3. What accident has happened along the face of cliff *U*? 4. Did it take place lately or a long time ago? Why? (Extensive landslides of this kind took place on the S. coast of England in 1839.)] 5. What part of 25 2 best indicates the general outline which the shore had before the cliff, spits, and reefs were formed? 6. Was the original outline more or less irregular than the present outline? 7. When a shore line is in the stage represented by 25 1, is its irregularity greater or less than in the initial stage? than in the stage of 25 2? [8. When the cliffs *Q*, *U*, *X* in 25 2 have been cut back about 200′ farther, what will have happened to the reef *ST*? to the hooked spit of the bay *B*? 9. Draw the shore line and the cliff crests [red] in that stage; shade [red] the cliff faces. 10. Draw the shore line and the cliff crests [blue] when the shore has been cut back to *W*; shade the cliffs [blue].] 11. Will the later changes in 25 2 make the shore line more or less irregular than now? 12. Will the extent of shore line bordered by cliffs increase or decrease? 13. Let the term *fully mature* be applied to a shore line that has been cut back of all the initial bay heads. Do cliffs form a greater fraction of the shore line in such a stage than in the stage of 25 2? 14. Compare in a general way the shore-line features of the initial stage, of early youth (25 1), of early maturity (25 2), and full maturity. [15. Which is greatest, the retreat of a cliff or the wearing down of the rock bench in front of it? Why? 16. How is the depth of the sea in deep water offshore from a cliff affected by the cutting of the shore cliffs?]

10. 1. In 27 2 sea cliffs are indicated by heavy hachures along the more exposed parts of the coast (the cliffs are given more breadth than they should have, in order to make them distinct); spits and reefs, by dotted belts at bay mouths; deltas and tidal marshes, by dotted spaces at bay heads and on bay sides. The high-water shore

is a heavy line; the low-water shore is a lighter line (omitted where the ragged rock bench has no beach). 2. Compare 27 1 and 2, beginning at SE. corner, and state how 27 2 differs from 27 1 along the outer coast SE. of bay *D*; at the entrance to the two E. branches of bay *D*; in the larger island on the NW. side of bay *D*; in the outer island between bays *D* and *C*; in the peninsula between bays *D* and *C*; along the NW. side of the isthmus of this peninsula; in the island between bays *C* and *B*; in the two small bays NE. of this island; between the inner and outer parts of bay *B* and of bay *A*; in all the bay heads. 3. Is the shore line of the spits and reefs at the bay mouths convex or concave to the sea? 4. Shade [light blue] in 27 2 the space where the sea has cut away the land. (The initial shore line of 27 1 is partly indicated by dotted lines in 27 2.) 5. Shade [light red] in 27 2 the reefs, inclosed lagoons, deltas, and tidal marsh.

11. 1. Why may the island on the NW. side of bay *D*, 27 1, be described in 27 2 as a *land-tied island remnant?* 2. Compare its isthmus with that of the *DC* peninsula, in 27 1, as to origin and material; with the isthmus of the land-tied island between bays *C* and *B*, 27 2, as to shape. 3. There is a small land-tied island at the head of bay *C*, 27 2; compare the manner of its becoming tied to the mainland with that of the other land-tied islands. [4. Part of the original NE. branch of bay *C*, 27 1, is now inclosed; compare the method of its inclosure with that of the small inclosed bay heads (lagoons) on the NW. side of the entrance to bay *C*. NOTE: Lagoons that are not entirely inclosed receive the salt water of flood tide through their inlets. Lagoons that are inclosed usually become fresh, as the original salt water slowly flows out through the sand reef and is replaced by water from the land. 5. Mark in 27 2 two salt lagoons, S; two fresh lagoons, F. 6. Show by [blue] arrows the direction in which reef material has been drifted by waves and currents in the spits on the E. side of bay *D*; in the spits between the outer and inner parts of bay *B*, and of bay *A*; in the reefs back of the land-tied island remnant between bays *C*

and *B*. 7. Has the coarser waste generally been drifted landward or seaward? Why?]

12. [1. Complete 27 2 *a* (with hachures, etc.), so that it shall show three reef-inclosed lagoons, one double-tied island remnant with a lagoon behind it, and one vanishing island with a spit behind it. 2. Complete 27 2 *b* (in contours, etc.), so as to show two reef-inclosed lagoons, with small deltas at their heads, and a 200′ cliff at the end of the middle headland. What is the contour interval? 3. Complete 27 2 *c*, so as to show the initial bay heads and the new-formed deltas in proper relation to the streams, and two spits nearly inclosing the bay; also (in broken lines) the former river system here dismembered by drowning. 4. Complete 27 2 *d*, showing two *delta-tied islands* and two *delta-inclosed lakes*. 5. Tidal currents are stronger in bays than on the outer shore line. The inflowing tidal current, or flood tide, of bay *C*, 27 2, is indicated by curved dotted lines. 6. The finer shore waste, when agitated by waves, is slowly drifted inward by the flood current; spits pointing inland may be thus formed. Print T by three such spits in bay *C*, 27 2.] [7. In what part of what state is the district of 39 2? 8. Mark [red] lines along the outside of five barrier beaches, inclosing lagoons. 9. Do the lagoons behind these beaches occupy all of the original bay heads? Explain. 10. Mark short [red] hachures (as in 27 2) where you think sea cliffs have been cut. 11. What name is given to a land-tied island? 12. Draw a heavy [blue] line to show the remaining parts of the original shore line. 13. Is the present shore line on the whole more or less irregular than the original shore line? 14. How was the original shore line produced? 15. What was the previous general form of the hills and valleys in this district? 16. Draw in 39 2 the original outline of the shore line.]

13. 1. What is the chief difference between the shore lines of 27 2 and 28 3? 2. In the change from 27 2 to 28 3, why has the SE. cliff increased in height? 3. Why have two lagoons of bay *D* been changed to tidal rivers? NOTE: Tidal rivers are very broad

in proportion to their length, because their volume is supplied by flood tide from the ocean, instead of by rainfall on the land; their current changes direction with the ebb and flow of the tide. 4. Why has the third lagoon of bay *D* disappeared? 5. What has happened to the land-tied island remnant and to the vanishing peninsula N. of bay *D*, 27 2? to the three islands in the upper part of bay *C*, 27 2? to the delta of river *C*? to the three lagoons of the *CB* headland? to the upper parts of bays *B* and *A*?

14. [1. What reason may be found in the form of 27 1 to suggest that the rocks around the bay heads *A* and *B* are much weaker than those about bay *D*? and that the rocks of the hilly peninsulas inclosing bay *B* are of intermediate hardness? 2. As long as pebbles and sand are supplied from the cliffs of the peninsulas, what forms will be built farther up bays *B* and *A*? (See 27 2.) 3. When the peninsulas are consumed (as in 28 3) and the weak rocks then exposed yield only fine waste to the cliff-cutting waves, where will (most of) the fine waste be swept? 4. In the absence of protecting barrier beaches, will the bay mouths be narrowed or widened by wave action? Will the bay heads be enlarged by wave action or filled with tide marsh? 5. How wide are the low-tide mud flats at the head of bays *A* and *B*, 28 3? 6. Compare these changes of bay heads *A* and *B* with those of the two small branch bays on the E. side of bay *D*. 7. What is the origin of the small island between bays *A* and *B*, 28 3?] 8. How far back have some of the headlands been cut in 28 3? (The initial shore line is indicated in 28 3 by single dots; the shore line of 27 2 by double dots.) 9. How far has the delta of river *C* been built forward? 10. How many islands have been tied to the mainland thereabouts? 11. Compare the shore lines of 27 1, 27 2, and 28 3 as to length, height, and continuity of cliffs; as to length and continuity of beaches; as to number of islands; of lagoons; as to length of headlands (from bay heads); as to general irregularity of outline; as to the number of natural harbors for large vessels (drawing 20′ or more) and for small vessels (drawing not more than 5′).

15. [1. Locate a city near the mouth of river *C*, 28 3. Where would you place a lighthouse near the entrance to bay *C*? Mark it LH. 2. Draw in 28 3 *a* the shore lines for three successive stages (see the guide lines; draw the first shore line dotted; the second, broken; the third, full); for the third outline indicate the cliffs, sand reefs, etc., as in 27 2 and 28 3. 3. In the first outline, how many small bays are partly inclosed by spits? wholly inclosed by reefs? 4. In the second outline, how many lagoons have been filled? how many destroyed by retreat of cliffs to lagoon head? 5. In the third outline, how many bays have disappeared entirely? how many remain as lagoons more or less filled with tide marsh? 6. In 28 3 *b* draw a new shore line showing changes such as have happened to bays *A* and *B* in 28 3. Indicate the shore cliffs and the low-tide line. How wide are the low-tide mud flats? 7. In 28 3 *c* note that the largest river enters the W. branch of the N. bay; let these bay heads be many miles from the exposed outer shore line. Draw three successive delta outlines for the seven streams. In the third outline, what has happened as to island tying? as to bay closing? as to river lengthening (for the largest river)?]

16. 1. Compare 28 3 and 4, as to irregularity of shore line. 2. In what part of 28 4 has the shore line been most simplified in the change from 28 3? (The outline in 28 3 is indicated in 28 4 by three-dot lines.) 3. Are the beaches more or less continuous than before? Explain. 4. Where are the beaches still interrupted? Why? 5. Where is the broadest space between high- and low-water lines? Why? 6. Why has the first SE. cliff retreated more than the second SE. cliff? the fifth less than the fourth? 7. Are the cliffs of 28 4 generally higher or lower than the cliffs of 28 3? of 27 2? of 27 1? Why? 8. In 28 4 *a*, will further retreat of the cliffs give them a greater or a less height? Explain. 9. Are any cliffs of decreasing height shown in 28 4? Mark — in front of them; mark + in front of the cliffs of increasing height. 10. In which of the four stages of shore-line development 27 1, 2, 28 3, 4, are protected harbors most common? Why? [11. The coast of California for

many miles N. and S. of the Golden Gate is about as harborless as the coast of 28 4.]

17. [1. Imagine some wet-weather streams flowing W. between the foreground hills of 28 4 *a*. Why may they be described as *beheaded by cliff retreat?* 2. Draw some dotted [blue] lines in 28 4 to show similarly beheaded wet-weather streams. 3. Examine 28 4 *b*. Is the small stream that comes down from the background hills as long as it used to be? Explain. 4. Why may such a stream be described as *betrunked by cliff retreat?* 5. Mark *BC* at the mouth of such a stream in the NW. part of 28 4. 6. Does the stream of 28 4 *b* enter the sea at grade (in accordant fashion), or by a hanging mouth (in discordant fashion)? 7. Are the streams of such hanging valleys likely to be large or small? Explain. 8. Compare this case with that of the side streams in the mountain gorge, Exercise V, § 12, question 9. 9. Mark H by the mouth of a hanging valley in the E. part of 28 4; in 1 1. 10. The dotted lines on the sea surface of 28 4 *a* represent the crests of successive waves driven by an E. wind. Where do they first break on the beach? Why? 11. How does the breaking wave then advance along the beach? Why? 12. Why would a man standing on the cliff top hear a continuous "roar" from a series of wind-driven waves? Compare the regular advance of such wind-driven waves along the beach in 28 4 *a*, with the arrival of a wave on the coast of 25 2. NOTE: In calm weather the advancing swell of a distant storm adjusts itself to the curves of a mature shore line, and falls over in surf almost simultaneously for distances of half a mile or more. 13. How does the sound of such surf differ from that of the wind-driven waves of question 12?]

18. [1. Compare the sea cliffs of 28 4 with the cliffs in the canyon of Exercise IV, as to relation to baselevel (sea level); as to relation to structure (the structure of the land mass in 28 4 may be taken to be similar to that of 25 1); as to uniformity of height (from base to top); as to occurrence of talus (the active attack of the waves at the base of a sea cliff prevents the accumulation of

much talus along the shore line); as to change in height of cliff face with advancing development; as to change in plan or pattern (as seen on a map) with advancing development.]

19. 1. Compare the shore line of 29 5 and 28 4 as to regularity (or simplicity) of outline; as to continuity of cliff front; as to continuity of beaches. 2. Explain the differences. 3. In what respects may the shore line of 29 5 be called "more fully mature" than that of 28 4? [4. Mark H opposite the mouths of two hanging valleys in 29 5.] 5. Compare the hilltop heights along the N. borders of 28 4 and 29 5. (The contour interval is 50′.) 6. Which is more rapid, marine erosion along the shore line, or subaërial weathering of the hills? 7. In 29 5 a stream flows SE. (in NW. part of figure); compare in 27 1 and 29 5 its fall (feet per mile), and the form (openness) of its valley. 8. Explain the differences. 9. Shade [light blue] the area of lost land in the SE. part of 29 5. 10. While the hills have been (slowly) worn down by weathering, and the shore line has been (more rapidly) worn back by the waves, what has happened to the rock bench offshore? NOTE: The down-wearing of a rock bench, a mile or more offshore, cannot be very rapid; but it must proceed as long as storm waves effectively jostle and grind the waste that lies on it. [11. Why will the outer (offshore) part of a rock bench be worn deepest? 12. The depth of the water in 29 5 along the original outer shore line, SE. of bay *D*, 27 1, may now be about 80′; at the original headland between the two E. branches of bay *D*, 27 1, 50′. The drowned valley of river *D*, 27 1, may now be partly filled with land waste, so that its depth at the inner and outer ends of the broken line in 29 5 is 60′ and 80′. 13. Enter these depths on 29 5 (several depths are already indicated there). 14. Draw sea-bottom contours in SE. part of 29 5 for 50′ and 100′. 15. Do these contours indicate that the surface there is smoother or rougher than the corresponding surface of 27 1? Explain.]

20. 1. In what respects does 29 6 resemble 29 5? 2. Draw in 29 6 a [blue] line corresponding to the mature cliff line of 29 5.

3. The broken lines in 29 6 are contours for 50′, 100′, and 150′. What movement (elevation or depression of the region with respect to sea level) has taken place since 29 5? 4. Did the movement occur soon after or long after the stage of shore-line development shown in 29 5? 5. What is the present altitude of the former shore line in the SE. part of 29 6? in the NW. part? 6. Was the movement by which 29 5 was changed to 29 6, of uniform amount in all parts? 7. How did it vary? 8. What name may the new land area be given? 9. In what exercise have land forms of this kind been already studied? 10. In what stage of development is the new land form of 29 6? Why? 11. Print B, C, D on the rivers of 29 6 corresponding to three bays of 27 1. 12. Why does such correspondence exist? 13. Why may the rivers on the coastal plain of 29 6 be classed as *consequent?* 14. Why may they be described as *extended by emergence* (or *elevation*)? 15. How many streams of 29 5 are now united in river *D*? 16. Why may these streams be described as *engrafted by emergence* (or *elevation*)? 17. What contrasted description was suggested for the streams of 27 1? (See § 3.) [18. To what class of land forms does the land of 29 5 belong? (The structure of the land may be taken as similar to that shown in 25 1 and 2.) 19. In what stage of development is the land area of 29 5? of 27 1? of the NE. part of 29 6? (As to 29 6, note whether the inland area is still in the same cycle of erosion with the two preceding figures, or whether that cycle has been interrupted by elevation and a new cycle thus introduced.) 20. Compare the sea cliff of 29 5 with the *elevated sea cliff* of 29 6, as to altitude of baseline; as to amount of talus at the base; as to steepness of cliff face. 21. Elevated sea cliffs occur at several different levels around the E. end of Cuba. What does this indicate?]

21. NOTE: 29 5 *a*, *b*, *c*, *d*, represent, in block diagrams, the changes in the shore line of a low coastal plain of weak (imperfectly consolidated) strata, fronting on a shallow ocean margin. The initial profile of the land and sea bottom is shown by a full (or broken) line. Slopes are much exaggerated. 1. While a very low

"cliff" is worn at *k*, 29 5 *a*, what has taken place at *n*? at *m*? NOTE: In a shore of this kind the water is so shallow that little of the storm-wave strength is spent on the land border; more of it is spent in agitating the loosened material at a moderate distance offshore, as about *n*. The coarser material is slowly shifted landward and forms a shoal, as at *m*; eventually the shoal is built up above sea level, forming a reef, and inclosing a lagoon; sand is blown from the reef beach into the lagoon, and the reef is broadened. 2. Draw the outline of a narrow reef on the sea surface of 29 5 *a*, and mark it R; mark the inclosed lagoon L. 3. The finer material shifted from *n* is carried seaward and deposited some distance offshore, beyond *q*. 4. Where is the sea bottom thus deepened? where made less deep? 5. How does the reef in 29 5 *b* differ from the reef drawn in 29 5 *a*? 6. Where has the material for the widened reef come from? 7. How has it been carried? 8. How has the depth changed at *n*? at *q*? Why? 9. How has the width of the lagoon been changed from 29 5 *a* to 5 *b*? 10. How is the tide marsh of the lagoon shown in the front section of 29 5 *b*? 11. Compare in 29 5 *b* and 5 *c* the breadth of the reef; the distance of the reef (outside) from the border of the mainland; the depth of the sea at *n*; at *q*. NOTE: The depth at *q* and *n* has been so much increased that the reef front is now attacked by the waves, and the reef retreats. 12. Why does some of the reef in 29 5 *c* lie on the tide marsh? 13. In some cases tide-marsh mud is found to "outcrop" on the outer beach of a reef. Draw a [red] profile in 29 5 *c* so as to represent this condition. Explain it. 14. As the retreat of the reef continues, what becomes of the lagoon? 15. Explain 29 5 *d*.

22. 1. Which part of the coastal plain, 29 6, has the strongest seaward slope? the weakest seaward slope? 2. Has an offshore sand reef been built opposite the part of stronger or of weaker slope? 3. Which part of the plain has been cut back in a low sea cliff? 4. Why has a reef been formed along one part of the shore line while a cliff has been cut along a neighboring part?

5. Where has most of the material for the reef come from? 6. Describe the change along the shore from the reef to the cliff. Explain it. 7. Why does the reef bend outward at a certain point? 8. Where is the reef interrupted by a tidal inlet? 9. On which side of the inlet is the reef set off (or offset) farther from the mainland? 10. From which direction does the prevalent longshore current come (see broken-line arrows)? 11. Make a rule, showing the relation between the offset of a sand reef at an inlet and the direction of the prevalent longshore current. 12. Which has the smoother outline, the outside or the inside of a sand reef? Why? [13. At times of heavy storm the waves may wash over the reef at certain points; the sand thus carried into the lagoon forms what may be called a *hurricane delta*. 14. Where does such a delta occur in 29 6? Compare its position with that of one of the small stream-made deltas.] 15. The sand, drifted along the beach reef, is swept at each inlet somewhat offshore by the ebb tide, and is carried into the lagoon by the flood tide. Why may such deposits be spoken of as *tidal deltas?* 16. Why is the tidal current stronger in the inlets than elsewhere? 17. What effect will the strong tidal current have on the depth of the inlet? NOTE: The outer tidal delta is commonly called a *bar*. 18. How will the depth of water on a bar at high tide affect the trade and growth of a village on the mainland shore of a neighboring lagoon? [19. A large part of the coast line of the Atlantic and Gulf coastal plain in the southeastern United States is fronted by sand reefs, broken by relatively shallow inlets. 20. What effect will this have on the growth of commercial cities along the coast? 21. In southern Texas a sand reef incloses a lagoon for 90 mi. without a break. What effect will this have on the growth of cities on that part of the coast?]

23. 1. To what part of 29 6 does 29 7 correspond? Compare 29 6 and 7 as to number of rivers and branches; as to fall of river *D* in feet per mile; as to prominence of the main river delta; as to area of tide marsh and lagoon; as to position of tidal inlet (measure distance alongshore from W. border); as to reef offset at the inlet;

as to length of cliffed shore line. 2. Explain the changes. 3. Suppose that the cliffed shore continues to retreat in 29 7, that the main delta continues to grow outward, and that the reef near the W. border of the figure is now retreating (see 29 5 *c*). Draw a [blue] line in 29 7 to show the shore line thus changed ($\frac{1}{8}$″ or $\frac{1}{4}$″ retreat at each end of shore line); another [blue] line to show a later change (in this line let the delta front be worn a little back); a third [blue] line to show a still later change (the whole shore line retreating). 4. On the third line is any of the original shore line of the coastal plain preserved? Where, and why? 5. What fraction of the total shore-line length is then cliffed? In what stage of development is the shore line so drawn? [6. Examine the E. branches of river *D*. Where is their fall most rapid? Why? 7. Draw a [red] line connecting these parts of most rapid fall. What may such a line be called? (See Exercise III, § 5.) 8. If 29 7 showed as much of the coastal plain as 29 6, what would be the general position of the fall line with respect to the coastal plain? to the oldland? 9. What peculiar feature appears in the oldland valleys of 29 7? Explain it. 10. Why may that part of the district be described as having "young valleys in the bottom of its older valleys"? 11. Draw a cross profile of these valleys.]

24. 1. By what process has 29 7 been transformed in 29 8? 2. What amount of regional movement has occurred? 3. Does the movement appear to have been uniform or of unlike amount in different parts? 4. Did the movement begin immediately after the stage reached in 29 7? How can you tell? 5. In what stage of erosion was the coastal plain when the movement began? 6. Does 29 8 represent a stage immediately after the movement ceased, or has some time passed since the movement ended? How can you tell? 7. Draw a [red] line to show the shore line of 29 8 as it was when the movement ceased. How does that shore line differ from the shore line printed in 29 8? 8. Why are some of the bays longer than others? Why do the bays branch? 9. In 27 1, 29 6 and 8, which one has a *shore line of (land) elevation?* a *shore line of*

(*land*) *depression?* 10. Which one has a simpler outline, a shore line of elevation or a shore line of depression? Why? 11. About how high are the little cliffs of 29 8? 12. How many bays (lagoons) are entirely inclosed by sand reefs? partly inclosed? 13. Which bays have fresh water? salt water? Why? 14. Locate a city in 29 8 so that it shall have a good harbor for ocean-going vessels and a convenient relation to the interior country. Explain the advantages of the point you select. 15. What is the present stage of shore-line development in 29 8? 16. Draw a [blue] line in 29 8 to show the shore line in a later stage of development (retreat of $\frac{1}{4}$–$\frac{1}{2}$ mile). 17. Draw a [red] line to show the fall line of 29 8. 18. Which parts of the streams may be called *revived?* [19. In what part of what state is the district shown in 27 1 *a*? 20. With which diagram in this exercise does it best correspond? 21. How many partial cycles of erosion are represented? (Remember that a movement of elevation or depression interrupts the preceding cycle at whatever stage it has reached, and introduces a new cycle.) 22. In what stage was the earlier cycle when it was interrupted? 23. Was it interrupted by a land movement of elevation or of depression? 24. What has happened since the new cycle was introduced? What stage has it now reached? 25. Draw a [red] line to show the shore line at the beginning of the new cycle. About how far have the shore cliffs retreated? 26. In what part of what state is 27 2 *e*? (It lies about 80 mi. ENE. of 35 1.) 27. How high is the shore cliff? In what stage of development is the shore line? 28. In what stage of development is the lacustrine coastal plain? 29. In what stage is the stream near the left end of the map? 30. Do the stages of development of the plain, the stream and valley, and the shore line agree or differ? Explain. 31. What opportunity for harborage is offered by such a shore line?] [32. Compare the first picture on the next page with the picture on page 17. In which case has the region recently been elevated? in which, depressed? How can you tell? 33. With which map of this exercise may the second picture on the next page be compared?]

25. 1. Define: § 3, rivers dismembered by submergence, embayed coast, half-drowned district; § 5, sea cliff, initial shore line, rock beach, high tide, low tide, tidal range, sea cave, rock arch, cove, chasm, stack, skerry, young shore line; § 6, beach; § 7, barrier beach, sand reef; § 8, tidal inlet, flood tide, ebb tide, lagoon, tide marsh; § 9, spit, hooked spit, initial (or original) shore line, young shore line, early mature shore line, fully mature shore line; § 11, land-tied island remnant; [§ 12, delta-tied island, delta-inclosed lakes;] § 17, streams betrunked by cliff retreat; § 20, rivers extended by emergence, rivers engrafted by emergence, elevated sea cliffs; [§ 22, hurricane delta;] § 24, shore line of elevation, shore line of depression.

EXERCISE X. THE DISTRIBUTION OF TEMPERATURE

OBJECT. **To learn the distribution of temperature over the world and its changes with the seasons.**

Preliminary. This exercise treats of the temperature of the lower air, near the surface of the land or sea. The temperature of the air is determined by the thermometer, placed where it is open to the wind but sheltered from sunshine and rain. The Fahrenheit scale is here used. Observations of temperature have been regularly taken, day after day, in many parts of the world for many years, and the results have been charted, as explained below; so that the distribution of temperature is easily studied by means of maps. This exercise uses Plates 30 and 31.

1. 1. The figures in 30 1 are records of temperature, such as might be determined by observations taken at the same hour in various parts of the central United States. In what states there shown do temperatures higher than 60° prevail at this time? temperatures lower than 10°? 2. Complete the line separating the part of the map where the temperature is over 40° from the part where the temperature is under 40°. What is the temperature of places on this line? NOTE: Such a line is called a line of equal temperature, or *isotherm*. 3. Print 40° at each end of the isotherm. 4. Draw the isotherms for 50°, 60°; for 30°, 20°, 10°, 0°. Print the proper numbers at each end of these isotherms. 5. Why is the distribution of temperature more clearly shown by the isotherms than by the separate observations? 6. Draw a line from SE. Texas across the map, to show the path you would follow in order to find the most rapid decrease of temperature; draw similar lines from S. Illinois; from SW. Tennessee. 7. Are these lines parallel? Are they straight? 8. What is the relative direction of the lines of temperature decrease,

or *lines of temperature gradient*, and the isotherms? 9. In what part of what state is the most rapid decrease of temperature, or the strongest temperature gradient, found? 10. In what part of the map is the decrease of temperature least rapid, or the temperature gradient weakest? 11. How is the strength or weakness of the temperature gradient indicated by the spacing of the isotherms? 12. How much stronger is the temperature gradient in E. Kansas than in Arkansas? How can you tell? 13. Draw three more temperature gradient lines across the map. What is their general direction? 14. If temperatures remain as in 30 1, in what directions might one travel from SW. Missouri to find no change of temperature? Would the path of travel be straight or curved?

2. 1. What is meant by the mean annual temperature of a place? (*DE*, 34.7.) How is it determined? 2. What does 30 2 show? 3. Shade lightly [red] all the space in 30 2 where the mean annual temperature is over 70°; [blue] under 30°. 4. Print ArCtic Cold Cap, N. Temperate Belt, Torrid Belt, S. Temperate Belt, AntarCtic Cold Cap on the five belts indicated by the shading and blank spaces on 30 2. 5. Why are two of these spaces called "caps," and the other three "belts"? 6. What countries of N. and S. America are in the several belts? of Europe and Africa? of Asia and Australia? 7. Which grand division of land (N. America, S. America, Europe, Asia, etc.) has the largest area in the Arctic cold cap? in the torrid belt? 8. In what belt is your school? 9. Draw a [blue] line along the isotherm of 50° in each hemisphere. In which belt is the 50° isotherm more regular? 10. Draw lines to show parallels of latitude 60° N. and S. (nearly halfway from the parallel of 40° to that of 80°). 11. Estimate the successive highest and lowest temperatures through which these lines pass. Print the figures indicating these temperatures in their proper places. 12. On which of these lines is the greatest temperature variation found? 13. Shade with vertical lines the areas of more than 80° mean annual temperature. 14. Do these areas lie chiefly on land or on water? 15. Shade in the same way the area of less than 10°. 16. Does it

extend farther toward the equator on land or on water? 17. Is the poleward decrease of temperature (poleward temperature gradient) in the N. temperate belt stronger on Asia or on the N. Atlantic? on the N. Pacific or on N. America? on northern continents or on northern oceans?

3. 1. What do 31 1 and 2 show? 2. On these maps shade the areas under 30° [light blue] and over 70° [light red]; shade more heavily the areas under 0° and over 80°. 3. Where are the hot regions (monthly mean over 80°) in January? in July? 4. Where are the very cold regions (monthly mean under 0°) in January? in July? 5. In what month have the hot regions the greatest area? the cold regions the greatest area? Why? (*DE*, 52.2; *G*, 245.3; *T*, 238.2.) 6. In what direction from your school is the nearest cold region in January? the nearest hot region in July? 7. Draw on 31 1 and 2 lines of temperature gradient through your school for January and July. What are the directions of these lines? NOTE: If the temperature maps extended farther south, a region of great cold would be shown near the South Pole in July. 8. In what parts of the world and in what month do the hot regions extend farthest from the equator? the very cold regions farthest towards the equator? Why?

4. 1. Make a mark across each meridian in 31 1 where the highest temperature occurs. 2. How do you determine where to place these marks? 3. Draw several N.–S. lines across the areas of over 80° (or 90°); place marks at the middle points of these lines. Draw a curved line through all the marks. 4. Why may this curve be called the *heat equator* for January? 5. Estimate the highest and lowest temperatures found on the January heat equator, and print their values in 31 1. 6. Draw in 31 2 the heat equator for July in the same way. 7. Copy the July heat equator (dotted line) on 31 1; shade with light vertical lines the belt between the two positions of the heat equator. What descriptive name can be given to the belt thus shaded? (Use the terms *migration*, *heat equator*, and *annual* in your answer.) [8. Mark a strong [red] N.–S. line where

the heat equator migrates from the geographic equator to 30° N. lat.; another where the migration is from 20° N. lat. to 20° S. lat.; from 15° N. to 20° S.; from 10° N. to 25° N.; from 5° S. to 40° N.; from 0° to 20° S.; from 5° S. to 15° S.] 9. Where is the migration of the heat equator of large value and about the same N. and S. of the geographic equator? Why? 10. Where is the greatest northern migration? Why? 11. Where does the belt of migration remain N. of the equator all the year (*DP*, 40.4, 40.9)? S. of the equator all the year? Why? 12. Does the heat equator migrate farther from the geographic equator on the continents or on the oceans? Why? 13. Is the belt of migration wider on the continents or on the oceans? Why? [14. Does the apparent annual migration of the sun carry it the same distance N. and S. of the geographic equator? How do you know? 15. Is the annual migration of the heat equator symmetrical? 16. Why do the two not agree?]

5. 1. During what months is the heat equator migrating northward? 2. What general changes of temperature take place in the N. hemisphere during these months? in the S. hemisphere? 3. What changes take place in these months in the slant of the sun's rays in the N. hemisphere? in the S. hemisphere? 4. What changes take place during the same months in the length of the days and nights in the N. hemisphere? in the S. hemisphere? (*DE*, 48.8–, 87.1–; *DP*, 400.1–; *G*, 21.3–; *T*, 400–.) 5. During what months does the heat equator migrate southward? Why? 6. What general changes in temperature are taking place in the two hemispheres during these months? Why? 7. Copy on 31 1 the isotherms of 40° from both hemispheres of 31 2. Shade with light vertical lines the belts thus indicated. 8. What names may be given to these belts? 9. Which is the wider and more irregular belt? Is it wider on the continents or on the oceans? Why? 10. Where is your school located with respect to one of these belts?

6. [1. Draw a meridian from top to bottom of 31 1 in 20° W. long. Lay a strip of paper along the meridian; mark on the edge of the strip where the equator and the successive isotherms are

crossed; print the values of the isotherms near their marks. 2. Place the strip along any horizontal line in 30 4 *a*, with north to right and the equator mark at EQ^R. Transfer the isotherm marks to the horizontal line, and indicate their values. 3. Make dots in 30 4 *a* at points above or below the transferred isotherm marks, so as to represent the value of the isotherms on the vertical temperature scale of 30 4 *a*. Draw a curve through the dots. 4. Draw a corresponding curve for July in 30 4 *a*. 5. Print JANUARY on one curve and JULY on the other. 6. What do these curves represent? 7. How is the migration of the heat equator indicated by the two curves? 8. Draw vertical lines in the space between the two curves. What do these lines represent? 9. About how much does the air temperature over the Atlantic change between January and July in the torrid belt? in the N. temperate belt? in the S. temperate belt? 10. Draw a meridian line of 20° E. long. from the S. border of 31 1 to the S. point of Africa; continue the line a little E. of N. to central Arabia; then NE. (through the small oval isotherm of −60°) to the Arctic ocean, and thence N. to the N. border of the map. 11. Mark EQ on the middle of a strip of paper; lay the strip on 31 1, keeping EQ on the equator and moving the strip parallel to the meridians; mark on the strip the points where the successive isotherms cross the line just drawn through Africa and Asia; indicate on the strip the values of the isotherms. 12. Transfer, as before, the isotherm marks to 31 4 *b*, and draw the January curve. 13. Do the same for July. 14. Print JANUARY and JULY on the curves. What do they represent? 15. How do they differ from the curves of 31 4 *a* as to the temperature of the heat equator? as to the migration of the heat equator? as to temperatures in far S. latitudes? in far N. latitudes? 16. What difference is shown by the two pairs of curves as to January-July temperature range in the N. hemisphere? in the S. hemisphere? 17. Why are these ranges greater in NE. Asia (31 4 *b*) than in the N. Atlantic (31 4 *a*)? 18. Draw vertical lines between the two curves of 31 4 *b*. What do they represent? 19. Mark arrowheads on the January end

of the vertical lines. Why do some of the arrows point upwards, some downwards?]

7. [NOTE: Let the *mean annual temperature range*, or difference between the means of the warmest and coolest months (not necessarily January or July near the equator) for many places be entered on a map of the world; let lines be drawn through points having equal annual range. Such lines are shown in 303. 1. What name may be given to this map? NOTE: Temperatures in far southern latitudes are not well known, but as far as 60° S. the annual range over the oceans is probably less than 20°. 2. Shade in 303 with dots the regions of less than 20° annual range. 3. Shade lightly with vertical lines the regions of more than 30° range; shade more heavily the regions of more than 60° range. 4. In what general parts of the world is the annual range of temperature small (under 20°)? large (over 60°)? 5. How is your school situated with respect to any one of these regions? 6. How are the characteristics of oceanic and of continental climates illustrated in 303? (*DE*, 50.7; *DP*, 41.6; *T*, 277.3.) 7. Draw several temperature gradient lines in different parts of 302; mark arrowheads on the lines to show the direction of temperature decrease. 8. What is the usual direction of temperature gradient lines in the N. hemisphere? in the S. hemisphere? 9. What is the direction of the January temperature gradient line (see 311) in Baffin bay (between Labrador and Greenland)? at North cape (N. point of Norway)? on NE. coast of Asia? 10. What is the direction of the July temperature gradient line (see 312) in S. California? in SE. Arabia? 11. State the cause of the unusual direction of the temperature gradient lines indicated in questions 9 and 10.]

8. Define: § 1, line of temperature gradient; § 4, heat equator; [§ 7, mean annual temperature range.]

EXERCISE XI. THE PREVAILING WINDS OF THE WORLD

OBJECT. **To learn the prevailing winds of various parts of the world, their changes with the seasons, and the control that they exert over the distribution of rainfall in different regions and in different seasons of the year.**

Preliminary. The prevailing winds for January and July are charted in 32 1 and 2, as determined by observations made in many different parts of the world on land and at sea. Winds are given the name of the direction from which they blow. The arrows on the charts fly with the winds: the heavier the arrow, the greater the average strength of the wind; the longer the arrow, the steadier the wind. Little circles indicate light variable winds with frequent calms. *Windward* means the direction from which the wind is blowing; *leeward* means the direction toward which the wind is blowing. The winds are stronger and more regular over the oceans than over the lands, where mountains and valleys affect their velocity and direction. Many of the following questions refer chiefly to the winds of the oceans. This exercise uses 32 1 and 2, 34 3 and 4.

1. 1. Examine the winds of the Atlantic ocean in 32 1. Print SW about the middle of the region where SW. winds prevail; NE, SE, NW, where corresponding winds prevail. 2. Draw a [blue] line in the N. Atlantic separating the westerly (NW., W., SW.) winds from the easterly (NE., E., SE.) winds. Prolong the line westward through the Gulf of Mexico; eastward across N. Africa and S. Asia. (This line should run square across N. or S. winds.) 3. Draw a [blue] line in the equatorial Atlantic separating the northerly (NE., N., NW.) winds from the southerly (SE., S., SW.)

winds. 4. Draw a line in the S. Atlantic separating the easterly (SE., E., NE.) winds from the westerly (NW., W., SW.) winds. 5. Do the same for the Pacific ocean (omit the W. Pacific); for the Indian ocean. 6. Print JAN. on the boundary lines that you have thus drawn in each ocean. 7. Connect the [blue] lines across the continents (omitting E. Asia), following the rules regarding wind directions already given. 8. Treat 32 2 in the same way, printing SW, NE, etc., in the several wind regions, and drawing [blue] lines separating the regions of unlike winds. 9. Print JULY on these lines.

2. 1. Around what part of the world, limited roughly by latitude circles, do NW. (or WNW.) winds prevail in January and July? 2. Why may this part of the world be spoken of as a *wind belt?* 3. Between what latitudes (roughly) do SE. winds for the most part prevail? NE. winds? SW. (or WSW.) winds? NOTE: Although the winds of these belts are somewhat irregular on the ocean (for example, the SE. wind belt in the W. Pacific for January), and are more or less interrupted on the continents, they are commonly spoken of as if they extended all around the world. 4. What names are ordinarily given to the several wind belts? (*DE*, 39.5–; *DP*, 30.1–; *G*, 258.3–; *T*, 259.4–.) 5. In which belts are the winds relatively steady? In which belts are winds less steady but stronger? 6. Do light winds and frequent calms prevail within the wind belts, or along the boundaries between them? 7. How many such belts of light winds and frequent calms are indicated? What names are given to them? (*DE*, 43.4, 44.5; *DP*, 32.5, 33.1; *G*, 260.1–4; *T*, 259.2, 261.9.)

3. 1. In which ocean are the westerly winds most uniform? Why? 2. In which northern ocean are the westerly winds most deflected from their usual WSW. direction in January? in July? 3. In which ocean are the trade winds most deflected from their usual course in January? in July? 4. Around which grand division of land (Europe, Asia, Africa, etc.) are the prevailing winds in July most deflected from the wind-belt directions? (Special account of

these deflected winds will be given in §§ 8 and 9.) 5. Which wind belt includes the greatest part of the United States? 6. On which coast (Atlantic or Pacific) of the United States do the winds therefore blow prevailingly from sea to land? from land to sea? 7. In what wind belt do Mexico and Central America lie? On which coast (northeast or southwest) do the winds there prevailingly blow from sea to land? from land to sea? 8. What part of S. America S. of the equator is covered by a belt of easterly winds? of westerly winds? 9. What parts of the coast of S. America S. of the equator have winds prevailingly from sea to land? from land to sea? 10. Answer the same questions for Africa S. of the equator. 11. What wind belt covers the greatest part of Africa N. of the equator? of Europe? 12. Compare the E. coast of N. America (Florida to Labrador) with the W. coast of Europe (Spain to Norway), as to prevalence of winds from land or from sea.

4. 1. What kind of weather prevails in the doldrums at sea (*DE*, 43.6; *DP*, 32.6; *G*, 260.1; *T*, 279.9)? in the trade-wind belts at sea (*DE*, 40.7; *DP*, 30.8, 52.7; *G*, 259.8)? in the horse latitudes at sea (*DE*, 44.7; *DP*, 33.2)? in the belts of westerly winds at sea (*DE*, 42.6; *DP*, 31.9; *G*, 258.7)? 2. How does the weather in the belt of westerly winds vary from winter to summer? (*DE*, 54.8; *DP*, 36.7.) 3. What kind of weather prevails in the Pacific ocean just N. of the equator, 140° W. long.? in the torrid Atlantic where you have printed NE and SE? in the N. and S. Atlantic where you have printed SW and NW? 4. Would *rainfall* (rain and snow) be more plentiful on coasts where the winds usually blow from sea to land, or from land to sea? 5. Shade [blue] in 32 2 the coasts (omit E. Asia for the present) in the belts of westerly winds where plentiful rainfall may be expected. 6. In what countries are these coasts? (Consult maps of continent, Plates 40–45, if necessary.)

5. 1. Would rainfall be more plentiful from winds that are blowing (obliquely) towards the pole, and therefore cooling, or from winds that are blowing (obliquely) towards the equator, and therefore warming? (*DE*, 40.4; *DP*, 30.6.) 2. Shade with [blue] lines the

coasts where the trade winds blow from sea to land (omit N. Africa); shade with [red] dots the coasts where the trade winds blow from land to sea, or parallel to the shore line. 3. Which of these coasts would have plentiful rainfall? Which would be dry or desert? 4. On which coast of Mexico and Central America would you expect the heavier rainfall? Why? 5. Why is the W. coast of SW. Africa a dry region, while the E. coast has a plentiful rainfall? 6. When moist winds blow across a high mountain range, ascending its windward slope and descending its leeward slope, which slope of the range will be rainy? which slope dry? (*DE*, 41.3; *DP*, 31.2.) 7. Would rainfall be plentiful or scanty on the interior lowlands to the leeward of such a range? 8. Consult the maps, Plates 40–45, and 32 1 and 2, and name the coasts where the prevailing winds encounter mountains as they blow from sea to land. 9. What can you say as to the rainfall of E. and W. Oregon? of California and Nevada? Explain. 10. Describe the relation of the Andes to the wind belts which cross these mountains; state the probable distribution of forests on the slopes of the Andes. 11. In what countries (see Plate 42) would the W. slope of the Andes be dry or desert? 12. Compare the rainfall in different parts of Peru and of Patagonia, with respect to the Andes and the prevailing winds. 13. What amount of rainfall would you expect on the mountainous islands, Sumatra and Borneo, between Asia and Australia? Explain. 14. On which slope of the volcanic mountains of the Hawaiian islands may the heavier rainfall be expected? 15. Where trade winds blow across nonmountainous interior regions and become warmer as they advance, would you expect plentiful or scanty rainfall? (*DE*, 41.1; *DP*, 30.8; *G*, 236.2; *T*, 281.8.) 16. Shade [red] the interior parts of N. and S. Africa and of Australia that are crossed by the trade winds but not visited by the doldrum belt or the horse-latitude belt. Would these regions be forested or desert? 17. In what parts of each continent are these regions?

6. [1. Copy [blue] on 32 1 the boundary lines of the wind belts (or belts of frequent calms) from 32 2. (Place these lines carefully

with respect to latitude lines and to points on the coast.) 2. Print JULY on the copied lines. 3. About what change of latitude takes place in the position of the boundaries of the wind belts (omit the Indian and W. Pacific ocean) from January to July? from July to January? 4. How does this change correspond with the change in the position of the sun in the sky for the same periods? 5. How does the amount of change compare in the two cases? 6. Compare the position of the doldrums in January and July with the position of the heat equator, 31 1 and 2, for the same months. 7. What seems to be the relation of the doldrums and the trade winds to the heat equator? NOTE: The heat equator in January and July is a better indication of the position of the doldrums on the lands in those months than is given by the winds of 32 1 and 2. 8. Copy on 32 1 the heat equator of Africa and S. America, 31 1 and 2; print JAN. and JULY on the copied lines, and let the migration of the doldrums on those continents be thus defined. 9. Shade with light vertical [blue] lines in 32 1 the belt across which the doldrums migrate. This belt may be called the *subequatorial belt.* 10. Shade in 32 1 the belts across which the calms of the horse latitudes migrate. These belts may be called the N. and S. *subtropical belts.*]

7. If § 6 is omitted, omit § 7 also. [1. What sort of weather will prevail at a place on the N. side of the subequatorial belt in January? in July? 2. What sort of weather at a place on the S. side of the same belt in January? in July? 3. What sort of weather at a place in the middle of the same belt in January? in April? in July? in October? 4. Draw a line around the area drained by the river Nile in Plate 45; shade lightly the river basin thus inclosed. Do the same for the Zambezi river in S. Africa. 5. In which month, January or July, will you expect high water in the Nile? in the Zambezi? Explain. (See the migration of the doldrum belt in Africa, 32 1.) 6. In what parts of Africa would you expect to find deserts? grass and trees? dense forests? NOTE: The heavier the rainfall of warm regions, the denser the tree growth. 7. The plains of the interior of Venezuela, lat. 5° N., have abundant rains

in July and August, but are dry in the opposite season; the plains of the interior of Brazil, lat. 10° S., have abundant rains from December to February, but are dry in the opposite season. Locate these plains on Plate 42, and account for their rainy and dry seasons. 8. Bogotá (locate on Plate 42) has abundant rainfall in April and May and in October and November, and a less rainfall in the other months. Account for these variations. 9. What sort of weather will prevail at a place in the N. subtropical belt in January? in July? 10. What sort of weather will prevail in the S. subtropical belt in January? in July? Explain. 11. In what months would you expect the rainy season in S. California? in Morocco and Algiers? Locate the last two countries on Plate 45. 12. In what months would you expect the rainy season in Chile, lat. 30° S.? in Cape Town, S. Africa? in S. Australia? in N. Australia?]

8. NOTE: The prevailing winds of the Indian ocean for January and July are shown in 34 3 and 4 on a larger scale than in 32 1 and 2. 1. In which month do the NE. trades of the Indian ocean seem to extend across the equator? 2. Why do they not stop at the equator? 3. What direction do they take after crossing the equator? 4. Shade lightly the space occupied by these extended and deflected trade winds in 34 3. 5. What is the direction of the winds in this region in July? (See 34 4.) 6. What name is given to winds that thus reverse their directions in the opposite seasons? (*DE*, 57.1; *DP*, 43.5; *G*, 262.1; *T*, 256.9.) 7. In which month do the SE. trades of the Indian ocean seem to cross the equator? 8. What direction do they take after crossing the equator? 9. To about what latitude are they then continued? 10. Why do they go farther N. than the extended NE. trades go S. of the equator? 11. Shade the region of the extended SE. trades in 34 4. 12. What is the direction of the prevailing winds in this region in January? (See 34 3.) 13. What two regions of monsoon winds are thus shown in the Indian ocean (and S. Asia)? 14. How are they situated with respect to the equator? 15. Which one is the larger? 16. What is the relation of the heat equator to these monsoon regions?

[17. Where else than in the Indian ocean do the NE. trades seem to cross the equator in January and extend into the S. hemisphere? (See 32 1.) 18. What is the direction of the winds between the equator and Australia in January? in July? 19. Why may these winds be called the Australian monsoons? 20. Shade [red] on 32 2 the region of these monsoons. 21. Where, besides in the Indian ocean, do the SE. trades seem to cross the equator in July and extend into the N. hemisphere? (See 32 2.) 22. In what small regions do these extended winds show a deflection from SE. to SW.? 23. What is the direction of the January winds in these regions? 24. What name may be given to the winds of these small regions? 25. Shade [red] these regions in 32 2. NOTE: It is probable that winds resembling monsoons, but less regular and less steady than the monsoons of the Indian ocean, occur in torrid Africa and S. America. 26. How many monsoon regions of this kind may be expected on these continents? 27. Draw in 32 2 two arrows in each of these monsoon regions, to show the expected wind directions in January [blue] and in July [red].]

9. 1. In what month does the heat equator advance upon S. Asia? 2. Compare the displacement of the heat equator from the geographic equator, as there shown, with the displacement in other parts of the world. 3. In what month does the air over Asia become warmer than the air over the oceans on the SE. and N.? colder than the air over the same oceans? 4. What would you expect as to the movement of the winds with respect to a region that is warmer than its surrounding oceans? colder than its surrounding oceans? (*DE*, 58.8–; *DP*, 42.2–; *G*, 262.2–; *T*, 257.1–.) 5. Do the winds of S., E., and N. Asia and the neighboring oceans, as shown in 32 1 and 2, confirm the answers to the preceding question? 6. What is the direction of the winds in China and on the neighboring sea in January? in July? 7. What name may be given to these winds? 8. In what months would you expect most rainfall in this region? Why? 9. In what months would you expect the most rainfall in S. Asia? Why? 10. On which coast of India

(SE. or SW.) would you expect most rainfall? Why? 11. What reasons can you give for expecting an unusually heavy rainfall on the S. slope of the Himalayas in July? 12. To what great monsoon system do the monsoons of the N. Indian ocean and the NW. Pacific ocean belong? 13. What amount of rainfall would you expect in central Asia in the colder half year? Explain. 14. What amount would you expect in the warmer half year? Explain. 15. What can you say about central Asia as to its habitability? 16. How is its habitability affected by the size of the continent? by the prevailing winds? by the distribution of mountains? (See Plate 45.) 17. What desert occupies the central part of this continent? What mountain ranges border this desert? 18. What smaller continent than Asia illustrates the problems of question 4? 19. Why do the plains of New Mexico and Colorado receive only a light rainfall? 20. Why does Arizona receive only a very small rainfall?

10. Define: Preliminary §, windward, leeward; § 2, wind belt, trade-wind belt, belts of prevailing westerly winds, doldrums, horse latitudes; § 4, rainfall; [§ 7, subequatorial belt, subtropical belts;] § 8, monsoons.

EXERCISE XII. WEATHER MAPS

OBJECT. **To study the causes of weather changes.**

Preliminary. The four figures of Plate 33 represent certain weather elements, such as might be determined by observations taken at the same hour at many different points in the central and eastern United States on a first, second, third, and fifth day. The chief weather elements are the temperature of the lower air (*DE*, 28.3, 31.6, 74.8; *DP*, 27.1–, 48.5–; *G*, 238.2, 246.3; *T*, 275.3, 420.3), pressure of the atmosphere (*DE*, 24.8–; *DP*, 23.4–; *G*, 225.6, 253.5–; *T*, 231.1–, 255.3), direction and strength of the wind (*DE*, 37.9–; *DP*, 44.4; *G*, 256.9–), and state of the sky (clear, cloudy, rain, or snow). Atmospheric pressure, as measured by the barometer, is expressed in "inches of mercury"; the values or "readings" usually found are about 29 or 30 inches. These are given in Plate 33 to tenths of an inch; 30.2 is printed 0.2; 29.7, as 9.7. On government weather maps pressure is given to hundredths of an inch. The places or "stations" of observation are represented on Plate 33 by the decimal points of the barometer readings. The winds are named by the direction from which they blow. Wind arrows fly with the wind; the stronger the wind, the longer the arrow. (See length of arrow for a wind of 20 mi. an hour, in SE. corner of 33 1.) Isotherms (see Exercise X, § 1) are printed in fine dotted lines; their values are indicated by numbers, meaning Fahrenheit degrees, as 30, 40, 50, at their ends. The scale of these weather maps may be taken as 320 mi. to an inch. This exercise uses only Plate 33.

1. NOTE: The pressure of the atmosphere (the observations having been reduced to a common standard, to make them comparable) is indicated for various places in 33 1. 1. In what part of the map

is the pressure more than 30.0? less than 30.0? 2. Complete the line through points (0.0) where the pressure is 30.0. Such a line is called an *isobaric line*, or *isobar*. Why? 3. Draw full black lines in 33 1 for the isobars of 30.1, 30.2, 30.3. 4. What is the form of the isobar of 30.3? Draw in similar form but smaller size the isobar of 30.4. 5. Draw isobars for 29.9, 29.8, 29.7. 6. What is the form of the isobar of 29.7? Draw in similar form but smaller size the isobars for 29.6, 29.5, 29.4. 7. Print A in the center of highest pressure; C in the center of lowest pressure. 8. Shade lightly [red] the area within the isobar of 30.3; and [blue] the area within the isobar of 29.7. 9. Print HIGH and LOW in these areas. 10. Describe briefly the dimensions and location of the areas of high and of low pressure.

2. 1. Draw a gently curving [red] line from the center of high pressure to the center of low pressure, crossing the isobars at right angles. 2. Why may this line be called a *line of pressure decrease*, or of *pressure gradient*, or of *barometric gradient?* 3. What is the distance in miles between the centers of high and low pressure? 4. How much decrease of pressure occurs along the line? 5. What is the average decrease of pressure in 100 mi.? 6. In what part of the map, with respect to the centers of high and low pressure, is the pressure decrease gradual (or barometric gradient weak)? is the pressure decrease rapid (or barometric gradient strong)? How can you tell? 7. Draw several other lines of barometric gradient outward from the center of high pressure; inward toward the center of low pressure. 8. Are the barometric gradients relatively strong or weak in the area of high pressure? in the area of low pressure? 9. What is the general velocity of the wind in the area of low pressure? 10. What strength of wind is indicated about the center of high pressure near the isobar of 30.4? near the isobar of 30.3? 11. What general relation seems to obtain between strength of barometric gradient and velocity of wind? 12. What (apparent) exception to this rule is indicated within the isobar of 29.4?

3. 1. Draw several light [blue] curved lines prolonging the wind arrows in 33 1, so as to indicate the general flow of the winds, especially about the areas of high and of low pressure. 2. Do the winds blow directly outward from the center of high pressure? directly inward toward the center of low pressure? 3. Turn the Atlas, so as to look along one of the barometric gradient lines, in the direction of pressure decrease. Do the winds near this line blow parallel to it, to the right of it, or to the left of it? 4. Test the answer to the previous question in several other parts of 33 1. 5. Make a general rule stating the relation of direction of wind to direction of barometric gradient; another stating the relation of strength of wind to strength of barometric gradient. NOTE: The winds in the area of high pressure may be described as "blowing gently along outflowing clockwise spirals." (*Clockwise* means "turning in the same direction as the hands of a clock"; *counter-clockwise* means "turning in the opposite direction.") 6. Make a similar statement for the winds in the area of low pressure.

4. NOTE: A set of observations made a day (24 hours) later than those in 33 1 is given in 33 2. 1. Prolong the wind arrows in light [blue] curved lines in different parts of 33 2. Draw similar lines in intermediate spaces. 2. What indication do these curved wind lines give of the occurrence of an area of low pressure? of an area of high pressure? 3. Complete in 33 2 the large oval isobar of 29.8, parts of which are printed in broken lines. 4. Complete the smaller oval isobar of 29.5. 5. Draw intermediate isobars for 29.6, 29.7; draw the isobar of 29.4 (about as far inside of 29.5 as 29.6 is outside of it). 6. Is there room for an isobar of 29.3? If so, draw it. 7. Shade lightly [blue] the area of low pressure, inside of the isobar of 29.7. Print C′ in the center of low pressure, and LOW across the area of low pressure. 8. Complete the isobars for 30.1, 30.4. Draw isobars for 29.9, 30.0, 30.2, 30.3. 9. In what state do you think an area of high pressure may have its center (outside of border of 33 2)? 10. Test in 33 2 the rules made in § 3, question 5, regarding the relations of wind and barometric gradient.

11. Draw a line inclosing all the stations where rainfall (rain or snow) is indicated in 33 2. In what states is rainfall indicated? (The rainfall dots should be somewhat larger inside the isobar of 29.6.) 12. What is the general position of the rainfall area with respect to the center of low pressure? 13. What general directions have the winds in the rainfall area? 14. Draw a line separating the region where the sky is clear from that in which it is cloudy or rainy. What is the general position of the clear region with respect to the center of low pressure? 15. In what general directions are the winds blowing in the clear region? 16. In what part of 33 2 may the weather be described as stormy?

5. 1. Examine the isotherms (fine dotted lines) in 33 2. What season do you think this weather map represents? 2. In what states may snow be falling? (*DE*, 70.2; *DP*, 45.5; *G*, 231.2; *T*, 249.6.) 3. Draw in light dotted [blue] lines the isotherms for every ten degrees, spacing them proportionately between and outside of the printed isotherms. (The isotherms of 80° should appear only in a small SE. corner of the map.) Print their values in small figures at their ends. 4. How much difference of temperature is there between places in the NW. and the SE. parts of the map? 5. Draw a [blue] dotted temperature gradient line across the map. 6. What is the average decrease of temperature in 100 mi.? 7. In what states is the temperature gradient strongest? What is the temperature decrease in 100 mi. in that part of the map? 8. What is the general direction of the winds in 33 2 where temperatures are above 40°? below 20°? 9. What relation seems to obtain between wind direction and temperature? 10. Prolong the southerly wind arrows backward, outside of the map. From what region do they come? 11. Answer the same question for the northerly winds. 12. How can you account for the unlike temperatures of these winds? (Examine 31 1.) 13. Now explain why the strongest temperature gradients occur in a certain part of 33 2.

6. 1. On which side of the center of low pressure in 33 1 would you expect relatively warm, cloudy, and wet weather? cold, clear,

and dry weather? 2. Mark C in 33 2 to show the location of the center of low pressure in 33 1. Draw a broken line in 33 2 connecting C and C'. 3. Why may this line be called the track of the low-pressure center, or the *storm track?* Prolong the track to the WSW. and ENE. 4. In what direction has the center of low pressure moved? How far has it moved in a day (24 hours)? How far, on the average, in an hour? 5. Draw in 33 1 a rainfall area somewhat smaller than that of 33 2, but in about the same position with respect to the center of low pressure. Mark some rainfall dots in this area (larger near C, smaller farther away). 6. Mark some clear-weather signs E. of the isobar of 30.0. 7. Draw a light [blue] dotted isotherm of 30° running NE.–SW. through the center of low pressure in 33 1; curve it to E. across S. Lake Michigan; SE. across Ohio and Virginia. Draw isotherms of 70° and 0° at about the same distances from the isotherm of 30° as they are in 33 2. 8. Describe the weather of SW. Missouri in 33 1; in 33 2. 9. How has the weather there changed in 24 hours, as to temperature? pressure? wind? sky? rainfall? 10. How are these changes related to the movement of the low-pressure area? 11. Describe the weather of SW. Pennsylvania in 33 1; in 33 2. 12. How has the weather there changed in 24 hours as to temperature? pressure? wind? sky? rainfall? 13. How are these changes related to the movement of the low-pressure area? 14. Mark a cross on the track of the low-pressure center, midway between its positions on the first and second days. How has the weather changed at this cross in 24 hours? 15. Is high pressure or low pressure associated with fair weather? with stormy weather?

7. [1. Draw two lines parallel to the track of the low-pressure center; one about 200 mi. to the N., the other as far to the S. Mark crosses on these lines opposite the cross at the midway point of the track. 2. Determine the changes of wind direction at these two crosses during the 24 hours from 33 1 to 33 2. 3. Compare these wind changes with those occurring at the cross on the track. NOTE: When the wind changes or shifts from E. through SE., S., SW., W.,

to NW., it is said to *veer;* when it shifts from E. through NE., N., to NW., it is said to *back.* 4. At which cross in 33 2 does the wind veer, as the low-pressure center passes eastward? At which cross does the wind back? 5. Where in the area of low pressure, 33 2, is the air calm? 6. Where is a similar calm space indicated in 33 1? NOTE: It happens not infrequently that a space of about 100 mi. diameter at the center of low pressure, or *storm center,* has light winds or calm air, and that the rainfall ceases there and the clouds break; hence this space has been called the *eye of the storm.* 7. In what direction and with what velocity is the wind blowing about 70 mi. E. of the storm center in 33 1 or 33 2? N. of the center? W. of the center? S. of the center? 8. With these facts in mind, correct, if necessary, your answer to question 14, § 6, as to the change in the winds as the storm center passes by.]

8. 1. Draw additional wind arrows in the E. part of 33 3, bearing in mind the rules made in answer to question 5, § 3. 2. Shade lightly [red] the area of (moderately) high pressure within the isobar of 30.1, and [blue] the area of low pressure within the isobar of 29.7. 3. In what state do you think the center of low pressure would be found? 4. Mark C″ to represent the center (near edge of the Atlas page). Estimate the pressure at C″. 5. Print C and C′ in 33 3 in the positions they had in 33 1 and 33 2. Connect C, C′, C″, by a storm-track line. 6. What is the direction of the storm track on the second day? 7. How far has the storm center moved on the second day? 8. What is its average hourly velocity for the second day? for the two days? 9. Compare the size of the area of low pressure (within isotherm of 29.7) and the pressure at the center on the three days. 10. How has this area of low pressure changed as it moved ENE.? 11. Do you think the area of high pressure in 33 3 represents a new position of the high-pressure area on 33 1, or of the high-pressure area inferred to stand NW. of 33 2? Why? 12. What features, already learned regarding the high-pressure area in 33 1, are again illustrated by the high-pressure area of 33 3, as to barometric gradients (direction and strength)? as to winds (direction,

strength, and general movement)? state of sky? 13. All these features of a high-pressure area, taken together, are given the name *anticyclone*. Print ANTICYCLONE across the area of high pressure in 33 3. 14. Compare the position of the isotherm of 0° in 33 1, 2, 3. How is its change of position related to the direction of the winds? to the movement of the center of low pressure? NOTE: A fall of temperature of 20° or more in 24 hours to a value below freezing (32°), accompanied by brisk or strong NW. winds, is called a *cold wave*. 15. In (about) what part of 33 2 is a cold wave occurring? In what part of 33 3? of 33 1? How can you tell? 16. In what direction does a cold wave advance over the central and eastern United States?

9. NOTE: The weather conditions of 33 4 are for the fifth day in this series of observations (the fourth day is not here mapped). 1. Draw a number of wind arrows of appropriate direction and length in 33 4. 2. In what direction and how far has the anticyclone of 33 3 moved in the interval between 33 3 and 4? 3. What is its average hourly velocity? 4. Do you think the area of low pressure on 33 4 corresponds with the one on the other maps? 5. What indications are found in 33 3 that a new area of low pressure is approaching? From what direction is it probably coming? 6. What features already learned regarding low-pressure areas in 33 1 and 2 are again illustrated in 33 4, as to barometric gradients? as to winds? as to state of sky? 7. All these features of a low-pressure area, taken together, are frequently given the name *cyclonic area* or *cyclone*. Print CYCLONE in its proper position in 33 4.

10. 1. Compare the position of the isotherm of 30° in 33 3 and 4. How is its change of position related to the direction of the winds? to the movement of the center of low pressure? 2. Why may the change thus illustrated be called a *warm wave?* 3. In what states was a warm wave taking place in 33 1? in 33 2? 4. Where may two warm waves be supposed to be taking place in connection with 33 3? 5. Where may a cold wave be inferred in 33 4? 6. Draw a cyclonic

track ENE. from the cyclonic center in 33 4. 7. Supposing that the progress of this cyclone is at about the same rate as that of 33 1, 2, indicate in 33 4 the position of the cyclonic center on the sixth day. 8. What sort of weather (temperature, pressure, wind, sky) is indicated for Chicago in 33 4? 9. What sort of weather will occur probably at Chicago on the following day? 10. What sort of weather is indicated for Buffalo on 33 4? 11. What sort of weather will probably occur at Buffalo one day later than 33 4? two days later? [12. In what part of 33 4 will the winds veer as the cyclonic area moves eastward? 13. Will veering or backing winds be more common in the United States in connection with this cyclonic storm?]

11. NOTE: Cyclonic storms of the kind here described occur chiefly in the belts of westerly winds, and are relatively rare in the trade-wind belts; they are more violent at sea than on land, and in winter than in summer. 1. Are cyclonic weather changes more common in Africa or in N. America? in S. America or in Asia? Why? 2. In what month would cyclones and anticyclones control the weather of the N. coast of Africa? that of the S. coast? 3. What sort of weather would probably be encountered by a vessel rounding Cape Horn (see Plate 42) in January? in July? 4. In what season would the change of temperature due to the passage of a cyclonic storm in the E. United States be greatest? Why? 5. Would the change of temperature due to the passage of a cyclonic storm in January be greater in the E. United States or in S. Europe? Why? 6. Why can weather predictions be made more accurately for the E. United States than for W. Europe? 7. In 32 1 represent by [blue] wind arrows a cyclonic storm of appropriate size (see 33 2) in the N. Atlantic. (Place the center of low pressure near 50° N. lat., 40° W. long.) 8. In 32 2 draw a similar cyclonic storm in the S. Atlantic (on the same meridian but in 50° S. lat.). NOTE: Cyclonic winds turn clockwise in the S. hemisphere. 9. Draw in 32 2 an anticyclone of appropriate area (see 33 3) in the N. Pacific (center of high pressure in 45° N. lat., 180° long.). 10. Draw a similar anticyclone in 32 1 in the S. Pacific (on the same

meridian but in 45° S. lat.). NOTE: The winds of anticyclones in the S. hemisphere blow outward, in counter-clockwise spirals. 11. What would be the direction of a warm inflowing wind in a cyclone in the S. hemisphere? of a cold inflowing wind? [12. What would be the succession of wind directions noted by an observer on the track of a cyclone in the S. hemisphere? on the equatorial side of the track? on the S. polar side of the track? 13. When one observer has cloudy and wet weather in a cyclonic area, what sort of weather will be noted by another observer who is under a neighboring anticyclone? 14. As the phases of the moon are the same for both these observers, what does your answer to the preceding question suggest as to the control of weather by the moon?]

12. Define: § 1, isobaric line, isobar; § 2, line of pressure decrease, pressure gradient, barometric gradient; § 3, clockwise, counter-clockwise; § 6, storm track; § 7, veer, back, storm center, eye of the storm; § 8, anticyclone, cold wave; § 9, cyclonic area, cyclone; § 10, warm wave.

EXERCISE XIII. OCEAN CURRENTS

OBJECT. **To learn the general system of ocean currents, the causes to which they are due, and their effects in modifying the distribution of atmospheric temperatures.**

Preliminary. The surface waters in the greater part of the oceans, to a depth of several hundred feet, are in slow movement at a rate of from 10 to 20 or 30, occasionally 60 or 80, (nautical) miles a day. The moving waters are called *currents;* but where a current is narrow, deep, and rapid it is called a *stream;* where it is broad, shallow, and slow it is called a *drift.* The prevailing direction of ocean currents has been determined in many parts of the world by the movement of floating objects, such as the wrecks of vessels, and in various other ways. The direction of currents is stated in terms of the point of the compass toward which they flow, as northward, southeastward, etc. The currents as charted in Plate 34 are represented in simplified form, without the irregularities that might be shown on a chart of larger scale. For the purposes of this exercise the "polar oceans" will be taken to extend to latitude 55° N. and S., and the other oceans will be sometimes spoken of as "nonpolar oceans." Distances in the nonpolar oceans on the charts here referred to may be roughly measured by noting that 40 latitude degrees equal 2400 nautical miles. This exercise uses Plate 34.

1. 1. What is the general direction of the ocean currents in latitude 40° or 50° N. or S. ? of the currents near the equator or the *equatorial currents?* (Do not consider for the present the currents shown by waving lines near the equator.) 2. What is the general direction of the currents near the eastern side of the nonpolar oceans? near the western side? (Use *equatorward* and *poleward,* instead of northward and southward, in answering this

question.) 3. Describe the general motion of the currents, when taken together, in each N. nonpolar ocean; in each S. nonpolar ocean. (Omit the N. part of the Indian ocean for the present.) 4. If you visited the central part of a nonpolar ocean and could see the currents moving around you, in which oceans would they turn *clockwise* (with the hands of a clock)? in which *counter-clockwise?* [5. If you stood at the N. pole and could see the earth turning in its daily rotation, would it appear to turn clockwise or the other way? 6. How would it appear to turn if you stood at the S. pole? 7. Compare the turning of the earth, as seen from the N. pole, with the turning of the currents in the two N. nonpolar oceans. 8. Make the same comparison for the S. hemisphere.] 9. Draw in the N. and S. nonpolar oceans of the ideal diagram, 34 2, some circular lines, with arrowheads, to show the general movement of currents appropriate to each ocean there mapped. In the center of each ocean draw a small circle, imitating a clock face, and indicate upon it direction of clockwise motion. NOTE: The general turning movement of the currents in each ocean may be called *eddies.* [10. About how long would it take a floating object to make a circuit of the N. Atlantic eddy? See the velocities stated in the preliminary section; estimate length of circuit in terms of degrees of latitude, and change degrees to nautical miles (60 to a degree).] 11. Should the eddies be described as fast moving or as slow moving?

2. 1. Examine the currents in 50° or 60° S. lat. in 34 1. (They will be better understood if examined on a globe.) If these currents were seen by an observer stationed at the S. Pole, how might he describe their general movement? [2. How does their movement compare with the direction of the earth's rotation?] 3. Why may these currents taken together be called the Antarctic eddy? 4. Do they seem to form a stream or a drift? 5. How is the Antarctic eddy related to the three eddies of the S. nonpolar oceans? 6. Why is there not an Arctic eddy, corresponding in size to the Antarctic eddy? NOTE: There is believed to be a relatively small Arctic eddy, flowing in a general way eastward around the

Arctic ocean. 7. Draw a light pencil line around the general course of the eddy in the N. Pacific ocean in 34 1. 8. Is the course circular or oval? 9. About how wide is it N.–S.? how wide E.–W.? 10. The W. part of this eddy is called the Japanese current. Why? 11. Describe the local currents in the NE. and NW. parts of the N. Pacific, in their relation to the main eddy. 12. Draw a line around the best defined eddy of the S. Pacific. What part of the ocean does this eddy occupy? 13. What are its rough dimensions N. S.? E.–W.? 14. The eastern part of this eddy is called the Peruvian current. Why? 15. What reasons can you suggest for the occurrence of a smaller eddy in the W. part of this ocean?

3. 1. Draw a pencil line around the eddy of the Indian ocean in 34 1. What are its rough dimensions? 2. How is it connected with the eddy of the Pacific ocean? 3. How are its currents related to Madagascar? to the S. point of Africa? 4. Draw a pencil line around the S. Atlantic eddy. What are its rough dimensions? 5. How does its shape differ from that of the Indian ocean eddy? 6. Does it receive a branch from the Indian ocean? 7. How does its SW. part differ from the corresponding part of the S. Pacific eddy? 8. Draw a pencil line around the N. Atlantic eddy. What are its rough dimensions? 9. What islands, sea, and gulf are on the SW. side of the N. Atlantic? 10. How are the currents of the N. Atlantic eddy related to these islands and seas? 11. The W. part of the N. Atlantic eddy, along the E. coast of the United States, is called the *Gulf stream*. Why? 12. Compare the breadth of the Gulf stream with that of the currents W. of Europe. 13. Why may the last-named currents be appropriately called the *N. Atlantic drift*? 14. How are the two Atlantic eddies connected? 15. What influence have the outlines of the bordering continents in causing the connecting current to cross the equator? [16. Draw in 34 2 a new [red] outline of the continents there shown, so that the eddy of the N. ocean shall give out a cross-equator connecting current to the eddy of the S. ocean; indicate this branch by [blue] arrows. In what direction does this connecting current flow? In

what direction does the actual connecting current flow across the equator in the Atlantic ocean ?]

4. 1. Compare the currents N. of the N. Atlantic eddy with those N. of the N. Pacific eddy, as to position ; as to direction ; as to dimensions. 2. Which of these far-northern currents may be described as an outgoing, poleward branch of the main eddy ? 3. Which may be described as wedging equatorward currents between the main eddy and the neighboring continent? 4. Which eddy of the S. oceans has an outgoing poleward branch ? Why does it occur in this ocean and not in the others ? 5. Compare its dimensions and position with those of the outgoing branch of the N. oceans. 6. Which ocean has the largest outgoing poleward branch from its main eddy ? Why ? 7. How does this branch seem to be connected with the eddy of the neighboring polar ocean ? 8. Which of the S. oceans receives an equatorward wedging current ? 9. How is the wedging current related to S. America ? 10. Why is such a current not found in the other S. oceans ? 11. Compare the breadth of open water connecting the N. Atlantic and the Arctic with that connecting the N. Pacific and the Arctic. 12. What currents are indicated in 34 1 in Bering strait ? (Such currents as occur there are small and unimportant in the general system of ocean currents.) 13. Compare the eddies of the two polar oceans as to size ; as to breadth of connection with the eddies of neighboring oceans. 14. What influence has the S. end of S. America on the eddies of the neighboring oceans ? Why ? 15. What influence has the E. point of S. America (Cape San Roque) on the eddies of the Atlantic ?

5. 1. Compare the general direction of the prevailing winds in far S. latitudes, as shown in 32 1 and 2, with the general circulation of the ocean currents in the S. polar (Antarctic) eddy. 2. Do the same for the three S. oceans ; for the two N. oceans. 3. Mark [blue] dots in 34 1 where the winds and currents have a general agreement in direction ; mark small [red] crosses where they differ. 4. Do the winds and currents generally agree or differ in direction ?

5. Which ordinarily has the greater velocity, the prevailing winds or the ocean currents? 6. What do the answers to questions 4 and 5 suggest as to the cause of the ocean currents? 7. Examine the small current of the Indian ocean, near the equator, for January, as shown by waving lines in 34 5. Why may this current be called an *equatorial counter current?* 8. What is its position with respect to the equator? 9. What is the direction of the winds in the same part of the ocean and in the same month? (See 34 3.) 10. What are the names of the two large N. embayments of the Indian ocean? (See Plate 44.) 11. In what month is the counter current of the Indian ocean N. of the equator? Describe its course. 12. How do the winds blow in that part of the ocean at that time? 13. How do the facts just learned bear on the answer given to question 6?

6. [1. In what other oceans do equatorial counter currents occur? (See 34 7 and 8.) 2. Describe the counter current of the Atlantic in January; in July. 3. In which of these months are the SE. trade winds extended over the greatest area N. of the equator? (See 32 1 and 2.) 4. What connection appears to exist between these extended trade winds and the counter current of the Atlantic? 5. Describe the counter currents of the Pacific in January; in July. 6. Where does the counter current in the Pacific, S. of the equator in January, stand in relation to the extension of the NE. trade winds S. of the equator? 7. What are the directions of the winds and currents in this part of the ocean in July? 8. Compare the counter current of the Pacific N. of the equator in January and July. In which month has this counter current its greatest development? 9. What general relation appears to exist between the extension of the trade winds across the equator, in the form of more or less perfectly developed monsoon winds, and the occurrence of equatorial counter currents? 10. In what parts of what oceans is this relation found? in what months?]

7. 1. On which side of the various current eddies, E. or W., would you expect to find relatively cool water? relatively warm water? Why? 2. Mark broken [or blue] arrows on the cool currents;

full-line [or red] arrows on the warm currents. 3. On which side, E. or W., of the torrid oceans should the equatorial currents have the highest temperature? 4. Mark [red] arrows along the equatorial currents in that half of their course. NOTE: The mean annual temperature of the ocean surface is shown by dotted isotherms in 34 1. 5. Shade [red] the area over 80° and [blue] under 40°. 6. Why do the isotherms of 70° turn towards the equator in the N. and in the S. Atlantic? in the N. and the S. Pacific? 7. Why is the 80° isotherm in the torrid Pacific limited to its W. part? 8. Why is the 40° isotherm deflected to an oblique course in the N. Pacific? 9. Why is the deflection of the 40° isotherm stronger in the N. Atlantic than in the N. Pacific?

8. 1. Examine the mean annual temperatures of the lower atmosphere in 30 2. Why are the isotherms of 80° nearer together on the E. side than on the W. side of the torrid Atlantic? 2. On which side (E. or W.) of the nonpolar oceans are the isotherms of 70° deflected equatorward? Why? 3. Where is the deflection greatest? Why? 4. Why is the 40° isotherm deflected to an oblique course over the N. Pacific? 5. Why is the deflection of this isotherm greatest in the N. Atlantic? 6. Over what ocean is the 30° isotherm deflected to the greatest distance from the equator? Why? 7. Why is there no corresponding deflection of the 30° isotherm over the S. Atlantic? 8. Why are the isotherms of 40° and 70° closer together on the W. side of the N. Pacific and N. Atlantic than on the E. side of these oceans? 9. Why are the corresponding isotherms over the Indian ocean so nearly parallel, instead of divergent, as over the N. oceans? NOTE: The annual change of temperature in the ocean surface is much less than in the atmosphere. 10. On which side (E. or W.) of the N. continents is the annual range of atmospheric temperature smallest? (See 30 3.) Why?

9. 1. Examine 31 1. Why does the January isotherm of 20° occur N. of Norway in the same latitude as that of −30°, N. of Alaska? 2. Why is the January temperature gradient in Alaska so much stronger than in Norway? 3. Suppose a sailing vessel

from a N. Atlantic port is bound for an Australian port; describe its course, so that it may take best advantage of winds and currents S. of lat. 30° S. Explain. 4. In what months might small sailing vessels most easily make the voyage from India to equatorial Africa? the return voyage? Why? 5. If a sailing vessel made a voyage from San Francisco to Japan and back, on which trip should it follow a more northern course? Why? [6. If a sailing vessel, bound from New York to Buenos Aires (see Plate 42), attempted to cross the equator N. of Cape San Roque, what sort of winds might it find on the heat equator? 7. How might the vessel be drifted by the currents in that part of the ocean? 8. Would it thus be helped or hindered on its voyage? 9. Where should the equator be crossed by such a vessel?]

10. Define: Preliminary §, currents, stream, drift; § 1, equatorial current, clockwise, counter-clockwise, eddy; § 3, Gulf stream, N. Atlantic drift; § 5, equatorial counter current.

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